

## FINAL REPORT FOR FREP PROJECT

a) Project title:

Development of an Educational Handbook on Fertigation for Grape Growers (MOU #M99-07)

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b) Statement of Objective: Briefly specify the problem being addressed by the project. The project objective(s) should be restated and consistent with the objective(s) of the original proposal.

This project is to develop an illustrated handbook for growers to assist them in developing environmentally safe and effective fertigation programs for their vineyards.

c) Executive Summary: Briefly describe and summarize the project tasks, milestones and products delivered. The primary focus of the book is on how to utilize drip irrigation systems to deliver fertilizers to grape vines. The book is illustrated and easy to read and understand. The following topics are covered:

- I. Nutritional needs of grape vines, and how to determine nutrient status in grape vines and soils
- II. Equipment needed for fertigation and how to design and install it (including backflow prevention)
- III. Water quality issues and cautions to prevent system clogging
- IV. Strategies for applying materials
- V. Fertilizer materials and their suitability for drip irrigation
- VI. Charts and tables to assist growers in determining concentrations and application amounts to apply to known vineyard areas
- VII. Environmental cautions on the storage and use of fertilizers, especially concentrated materials
- VIII. Monitoring to measure the effectiveness of the fertilizer applications

(Sections a, b and c combined should not exceed two pages)

d) Work Description: Work description should be identified by tasks and subtask numbers as they appear in your contract and include a descriptive title.

1. Develop a detailed outline of the book.
2. Review of existing literature, particularly in the area of Environmental Horticulture
3. Write the text.
4. Develop needed materials that do not exist, such as photographs and engineering diagrams of injection systems in vineyards, charts and tables of dilution rates of concentrated materials into parts per million, maximum fertilizer concentrations for stock solutions, etc.
5. Develop the publication so that it is attractively laid out, easy to read and comprehend, and practical in its information.
6. Submit for peer review and publication.

Comments: We have accomplished all of these tasks, with the exception that we are on item 6, which will occur before item 5. Item 5 is not completed, but a draft version of the publication has been submitted, and we are underway with ANR Publications.

e) Results, Discussion and Conclusions:

Following a very complete review of the literature, the book was written according to our outline. Up to this point, there was no comprehensive source of information specifically on grape vine fertigation. Since almost all vineyards

planted since 1995 have a drip irrigation system, this is a timely and potentially very useful document. At this point, the publication has been submitted to UC ANR Publications and is in the review and development process.

When the project was originally conceived, it wasn't stated how the book would be published. Originally, it was considered to have a commercial press do the publication, but it became clear that having UC do the publication would be more effective. Under the UC publication process, there will be peer review, which will strengthen the quality of the information. Additionally, UC will fund the printing, and also distribute it through California, the US and the world.

- f) Project Evaluation: The following (when applicable) will be included in this section - Cost/Benefit analysis of adoption of the new technology, barriers to adoption, and evaluation of the effectiveness of selected outreach/information dissemination activities (refer to section 2.8).

At this point, it is too early to tell how effective this publication will be. Since there are over 700,000 acres of vineyards in the state, we know that there are many potential clients for this kind of a publication.

- g) Outreach activities summary: Include the following information: Date, place and name of event, presentation title, and number of participants, audience and supporting documentation (i.e., flyers, program, etc.).

There have been none at this point. When the publication is completed and printed, UC Communication Services will promote the book with press releases and review copies to all farm advisors and selected media contacts. The book will also be placed in the ANR Publications Catalog, and the UC Davis Bookstore, both of which contain fairly extensive offerings on viticultural publications.



## I. INTRODUCTION

In the 1990's, drip irrigation became widely used in the vineyard industry due to its potential for accurate and uniform placement of water beneath the vines, wetting only the soil and not the vine. Low precipitation rates also made it possible to irrigate soils on hillsides and other locations without excessive runoff or erosion. Drip system requirements of low pressure and flow rates help stretch limited water supplies, and use smaller pumps that use less energy than conventional sprinkler systems. It is no wonder that the vineyard industry readily adopted drip irrigation.

When drip systems are properly designed, installed and maintained, they can apply water very uniformly to a vineyard. Another potential advantage is that they can also deliver water soluble fertilizers uniformly through the system to the vines, and assist the grower in providing adequate nutrition for plant growth along with the water needed for optimal fruit yield. This practice is known as *fertigation*.

Selecting the proper fertilizer, injecting the material in the right concentration and in a manner that insures that it is uniformly distributed through the vineyard requires both knowledge, skill and care. The purpose of this publication is to assist the vineyard manager in perfecting their fertigation practices. The content of this book is focused specially on microirrigation systems, especially drip systems. Following are brief discussions of the overall content of this publication.

### **Adequate nutrition for fruit quality and yields**

Grape vines vary in their need for nutrients based on the soil they are planted in, the varietal being grown, and the expected tonnage of fruit in the vineyard. Grape vines differ from many other crops in that their fertilizer needs tend to be very modest. In most cases, a soil fertility program will not be based solely on fertigation, as soluble fertilizers are often more costly than other options. Additionally, not all nutrients are soluble enough to move readily to the root system when applied to the soil. Consideration for overall soil health and vine nutrition may include applications of composts, growing nitrogen fixing cover crops and fertilizers that mineralize and release nutrients slowly over time. These practices help to build aggregate stability, protect the soil from erosion and improve the infiltration of water and air to the root system. The physical conditions of vineyard soil are every bit as important as nutrient status for healthy vine grown.

Fertigation can be a useful way to augment nutrients when plant and soil tissue testing indicate a deficiency, and a need for timely and accurate applications of materials. In some cases, fertigation may be the best approach to providing nutrients for vines if the vineyard is planted on soils with very low fertility, and irrigation occurs frequently.

Fertigation needs to be done carefully. Overfertilizing for big crops may result in poor quality fruit (lack of flavor concentration and color) and overly vegetative vines, which in time will actually decrease yields. In general, many growers fertilize regularly with



nitrogen, potassium and some micronutrients, including zinc and boron. Less commonly, growers may need to apply iron, magnesium and manganese. Phosphorus is rarely deficient, but under low and high pH soil conditions, it may be necessary to apply this nutrient to vines. In some cases, irrigation water may need to be treated with acidifying materials or chlorine to prevent clogging, and improve nutrient uptake. Since vineyard conditions vary greatly around the state, it is necessary to talk to local farm advisors, winery representatives, viticulture consultants, growers, and other industry professionals to develop a fertigation program that is right for your vineyard.

### **Environmentally safe applications of fertilizers**

Since many of the fertilizer materials that we put through a drip system are water soluble, they can travel easily wherever water goes. The object of any fertilizer application is to insure that the nutrients are utilized to the greatest extent possible by the crop. Keeping fertilizer out of surface water and ground water is critically important, and increasingly, there is monitoring by regional water quality control boards following US Environmental Protection Agency Clean Water Act enforcement procedures. Willful noncompliance with EPA guidelines will almost certainly result in legal action and fines. Fertilizer applications should follow “Best Management Practices” that are based on optimum timing for nutrient uptake; applying the amount of materials that are actually needed by the crop; delivering fertilizers accurately to the root zone; and installing back flow prevention devices that protect the irrigation source from accidental contamination. It is also important to store, mix and hold concentrated fertilizer stock solutions in places where accidental spills or discharges are contained, and prevented from moving off site. Containment structures should be installed around areas where spills of concentrated materials might occur. Overall, the operating philosophy is that it is cheaper and easier to keep water from being contaminated than it is to clean water after it has become polluted.

Some of the materials used to fertilize grape vines or maintain the irrigation system are potentially toxic, caustic or otherwise harmful to people. Understanding the proper storage and handling of these materials is critical to all people likely to be near the systems when they are operating. Appropriate protective clothing should be used when handling concentrated materials. Another important safety feature is to insure that should the main irrigation pump fail, or water in the main lines stop flowing, that the injection system also shuts off. Otherwise, undiluted concentrated material will be pumped into the system while it isn't operating. It is also important to have back flow preventers on the chemical supply tank lines to the irrigation system, so that accidental overflows can't occur.

### **Cost effective applications of materials**

Getting the greatest value and effectiveness for your efforts is an integral part of successful farming. There are many benefits to using fertigation from a financial perspective:

- a. You are already spending the energy to apply water, so it requires little



additional energy to inject fertilizer. This material can be very accurately distributed through the vineyard with minimal amounts of labor. Frequently, this will require less energy, labor and money than other mechanical or hand applications.

- b. Fertigation equipment may be less expensive than ground application devices. Frequently, maintenance is very low on fertigation systems, and not expensive.
- c. When fertigating, smaller amounts of fertilizer material may be needed than ground applications, since the fertilizer is so accurately applied to the root zone, where active feeder roots are present.
- d. Nutrients can be applied to the soil when conditions from weather or pest management reentry times might otherwise prevent applications with conventional equipment.
- e. Nutrients can be applied with great accuracy and efficiency when the system is designed and built with good equipment; properly calibrated, and applications are done properly.
- f. Less damage to the crop root system is likely to occur compared to fertilizer materials that require physical incorporation by tillage.
- g. Fertigation is not nearly as weather dependant compared to materials that require rainfall to be incorporated. Consequently, the likelihood of material lost to volatilization is remote.

Choosing the right fertilizer for your situation is also important, as the cost of materials varies greatly. Applying materials at the right time of the year, in the right concentration, and the right frequency is part of the information that you need to develop a cost effective fertigation program.

#### **Fertigation System Maintenance and Effectiveness**

Care must be taken to insure that all parts of the irrigation system function well. With good maintenance and careful use, a well designed system will continue to perform to specifications for many years. Challenges arise when irrigation water quality might cause the system to clog due to chemical, physical or biological problems. By injecting fertilizers into the system, these conditions can also worsen. Careful assessment is needed early in the design and management process, as conditions can arise that permanently damage the system or its equipment. Knowing what factors are likely to cause a problem, and how to prevent clogging is an important part of managing your system. Periodic testing of output, chemical conditioning of the lines and emitters, and flushing are important maintenance procedures. Providing adequate time to inject materials, and adequate time to be sure that fertilizers have cleared through the irrigation lines is important.

Fertigation is another tool that allows a vineyard manager to grow high quality fruit. This publication will assist growers in learning the information needed to implement a successful and efficient fertigation program.



## **II. Grape Vine Nutrition**

*By Pete Christensen, William Peacock and Glenn McGourty*

Wine grapes are well adapted to a wide range of soil types and fertility levels. Wine grapes can perform well in surprisingly shallow and infertile soils. Many wine growers deliberately look for these sites, as concentration of flavor and pigments can be intense if the vines have their basic needs met for nutrition and water, without encouraging excessive vegetative growth. In general, grape vines have fewer mineral deficiency problems, and require a lower level of fertility than most horticultural crops. Most wine growers focus on providing adequate potassium and nitrogen for their vines. Other deficiencies are less common, but can drastically affect crop yields and quality. Some nutrient excesses can also be harmful.

Sixteen elements are known to be necessary for normal plant growth: carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, zinc, boron, iron, manganese, copper, molybdenum and chlorine. Carbon, hydrogen and oxygen are taken in from the air and water by plants. The remaining nutrients are absorbed from the soil by the roots. These thirteen remaining nutrients are broken up into two groups, *macronutrients* (nutrients used in large quantities, expressed in pounds/acre) . Macronutrients include nitrogen, potassium, phosphorus and sulfur. Micronutrients (nutrients used in small quantities, ounces per acre) include zinc, boron, iron, manganese, copper, molybdenum, and chlorine.

### **A. Grapevines and Macronutrients**

#### **1. Nitrogen (n):**

##### **Importance**

Nitrogen is widely needed in many vineyards, especially in the San Joaquin Valley where vines tend to be large. In the North and Central Coast regions, smaller amounts of nitrogen are required. Typically, relatively low amounts are applied on an annual basis, especially compared to other horticultural crops. Vines do not always show obvious deficiency symptoms. Usually reduced canopy growth and fruit yields occur before visual symptoms are observed. Excessive nitrogen can cause rank growth, predispose the vines to insect and disease attack, fruit shatter, and eventually, reduced fruit set and poor wine grape quality.

##### **Soil Sources**

Nitrogen occurs in native soils as the end product of decomposed plant and animal tissues that make up a soil's organic matter. Unlike other nutrients, nitrogen is not derived from soil minerals.

Nitrogen can also be fixed from the atmosphere by rhizobium bacteria that form nodules on leguminous plants such as alfalfa, clovers, vetches, peas and beans. Cover crops can easily fix adequate nitrogen for most vineyards.



Rain water, irrigation water and well water can also be additional sources of nitrogen. It is a good idea to periodically check your irrigation source for nitrogen, as it can supply a portion of the vineyards need in some situations.

### **Role**

Nitrogen is used by plants to make proteins that make up protoplasm, the basic living part of plant cells. Nitrogen is an important constituent of amino acids, lecithins and chlorophyll. Deficiencies slow plant growth and cause carbohydrate reserves to increase. Excesses contribute to excessive growth and reduced carbohydrate accumulation.

### **Uptake and Utilization**

Grapevines absorb most nitrogen in the nitrate form and move it readily to the leaves. Once there, it is metabolized into amino acids, proteins and other nitrogen containing compounds. Conversion from nitrates to these compounds is dependant on temperatures and plant enzyme (nitrate reductase) contents that vary between varieties. Varieties with high enzyme content may be quite efficient at converting nitrates, and have low nitrate content. Others may be less efficient, and have higher nitrate content. Consequently, there are no universal standards for all varieties on nitrogen content in the vine tissue. Cool weather and low light conditions can also affect the conversion process, and may cause high nitrate levels in the plant some years.

### **Diagnosis of N Needs:**

#### **Deficiency**

Plants low in nitrogen do not always show visual symptoms unless deficiencies are severe. Pale green to yellowish color of the foliage, poor shoot growth and low vigor are symptoms associated with nitrogen deficiency. Root systems impaired by insects, diseases, or poor physical conditions in the soil may be the actual cause of the deficiency, and also need to be considered when diagnosing this deficiency.

#### **Excesses**

Plants with excess nitrogen frequently have a dark green color, vigorous shoots, long internodes and somewhat flattened stems. Because of shading, many canes are green going into dormancy, making them more prone to freeze damage in cold areas. Often, buds are less fertile due to shading, and vigorous shoots may not make the best choices for fruiting wood during pruning. Vines with high nitrate content have also been noted to be more susceptible to leaf hopper infestations, and powdery mildew and bunch rot attacks.

Under excessively high soil nitrogen conditions, temporary toxicity may occur in the spring when cool weather follows periods of hot weather. The petioles of affected leaves have high nitrate levels. Mostly the older leaves are affected. They have a deep green color, and often have glossy patches on the upper leaf surface. Protein compounds (amino acids) exude from pores (hydathodes) at the leaf edges, leaving a white, salt like deposit. In severe cases, tissue at the leaf edges and sometimes entire leaves die. Close examination may reveal a water-soaked appearance of some of the blade tissue before it



turns brown. Symptoms are usually short lived, and occur before bloom. Warm weather encourages rapid nitrogen uptake, followed by inadequate assimilation and utilization of nitrogen compounds in the new growth. Toxic levels of nitrates or intermediate compounds then concentrate during the cool weather. Vines typically start to grow normally once warm weather returns.

Young vines 1 to 3 years old some times show leaf burn when they are excessively fertilized. Symptoms include marginal browning of the leaves. In severe cases, all of the leaves turn brown. Plant tissue testing should show a high content of nitrogen. Symptoms can be alleviated by discontinuing fertilizing, and applying heavy irrigations to leach some of the fertilizer through the root zone.

### **Suitability of Fertigation to Apply Nitrogen**

Nitrogen can be easily and successfully applied through fertigation. There are numerous soluble fertilizers that can be applied inexpensively through microirrigation systems.

## ***2. Potassium***

### **Importance**

Potassium deficiency is common in the North Coast, and less common in the San Joaquin Valley growing areas. Parent rock materials affect the availability of potassium in many areas. Soils formed from granitic rocks tend to have adequate potassium (San Joaquin Valley). Soils formed from serpentine rocks high in magnesium can often be borderline or deficient (Coast Range). Potassium tends to be stable in the soil, and doesn't readily leach. Clay mineral types can also detrimentally affect exchange rates, as potassium ions may be held tightly between alumina-silicate layers. Grape vines do use large amounts of potassium in amounts comparable to nitrogen.

### **Sources in the Soil**

Most potassium in soils is derived from weathered minerals, especially feldspars and micas. These minerals are only slightly soluble and are found as large size particles. As the particles weather, potassium is solubilized and becomes available to plants as positively charged ions. These ions are held mostly by the cation exchange complex associated with clay colloids or organic matter in the soil. While there may be fairly large amounts of potassium in a given soil, most of it is insoluble, and only a small percentage is available to plants.

Potassium fertilizers applied to the soil often are "fixed" or held to the cation exchange complex and slowly released over time. Clays and clay loams are most likely to fix the most potassium. Sands and sandy loams fix less potassium, but are more prone to potassium leaching, and showing deficiencies. In any case, potassium leaches slowly and doesn't move readily into the soil profile.



apply this nutrient. Soluble forms such as ammonium polyphosphate and phosphoric acids are used in fertigation. Ammonium phosphate can be injected at very low rates. It is critical to evaluate your irrigation water quality before injecting any phosphates into a microirrigation system. High levels of carbonate/bicarbonate along with calcium will almost certainly precipitate into highly insoluble calcium pyrophosphates, causing extreme clogging problems in emitters.

If phosphorus is deficient, many crop consultants recommend that soil applications of phosphorus also be made along with fertigation to insure that long term deficiencies are corrected. There may be other factors that need to be addressed, such as correcting extremes of pH with the appropriate soil amendments.

#### ***4. Magnesium***

##### **Importance**

Magnesium deficiency in grapevines is rare in California, generally occurring only when vineyards are planted on sandy soils with low cation exchange capacities (CEC). Some rootstocks and varieties may show deficiencies when others don't, such as the rootstock 44-53 and the varieties Grenache, Thompson Seedless, Barbera, Malbec and Gamay. Young vines are the most susceptible to deficiencies, and often, symptoms disappear as vine root systems expand into subsoils higher in magnesium. Deficiencies sometimes occur in topsoil fill areas resulting from land leveling, especially if the fill soils are sandy. In other areas, magnesium sometimes is deficient following heavy applications of potassium fertilizer. This has not been documented to occur in California.

##### **Soil Availability and Uptake**

California soils generally have high levels of available magnesium, and in some instances, excessive amounts. The mineral sources are dolomite, biotite and serpentinite. Plants absorb magnesium as the  $Mg^{++}$  ion from the cation exchange complex where like potassium it is attached to negatively charged clay particles and organic matter. The roots extract potassium either from the soil solution, or from contact with soil colloids.

##### **Role and Utilization**

Magnesium is a constituent of chlorophyll and is essential for photosynthesis. Magnesium also activates many plant enzymes required for growth. Magnesium is highly mobile within plants and can be readily translocated from older to younger tissue when deficiency levels are occurring.

##### **Symptoms and Diagnosis of Deficiency**

Deficient vines show deficiencies by basal leaves becoming chlorotic (yellowing) normally after mid season. This will progress up the stems to the young leaves. Chlorosis begins on the leaf margins and moves inwardly between the primary and secondary veins. Some border of normal green color remains along the veins, and may become almost creamy white. Frequently the chlorosis is followed by leaf margin burn. Many red fruited varieties also show a reddish border inside the burned perimeter of



tissue. Symptoms become more severe with large crop loads, and are most obvious as fruit becomes ripe.

### **Magnesium Excesses**

In soils derived from serpentine rocks, there often are very large amounts of magnesium. Frequently these soils are poorly structured, low in potassium and may have both nickel and manganese present in toxic amounts. These areas should be carefully evaluated as suitable sites for a vineyard. If the site is sloping, it may also be very unstable when wet, and prone to slippage. Vines often grow poorly in these locations, and potassium frequently is deficient. Corrective actions will involve large applications of gypsum (preplant if possible), soluble forms of potassium applied through the microirrigation system, potassium sulfate applied to the soil in large quantities, and cover cropping, compost applications and other practices that help to improve soil structure.

### **Fertilization and Responses to Magnesium**

Magnesium deficiencies are not common in California, and may not be economically important enough to treat. If symptoms are occurring by midsummer, it may be advisable to treat the vineyard. Suggested rates are 2 to 4 lbs of magnesium sulfate (Epsom salts) per vine. It may take several seasons for the fertilizer to take effect.

### **Suitability of Fertigation to Apply Magnesium**

Magnesium sulfate can easily be supplied to vines by fertigation. Do not use any other fertilizers containing phosphorus or calcium, as precipitation and plugging may occur. Magnesium precipitates can also form if carbonates are present in the water, so be sure to flush the system well after injections.

## **B. Grapevines and Micronutrients**

### *1. Zinc*

#### **Importance**

Zinc deficiency is common in many California vineyards, and many growers routinely fertilize for this problem. It is most common in the San Joaquin Valley and the Central Coast regions, and somewhat rare in the North Coast. The deficiency is sometimes referred to as "little leaf disease".

#### **Sources in the Soil**

Zinc is found in minute quantities in most soils, and sandy soils have the lowest levels overall. The product of weathered minerals, zinc is adsorbed by clay and organic matter and held in an exchangeable condition. Zinc levels are highest in the upper horizons of the soil, especially where organic matter is being cycled from crop residues.

Zinc becomes less available at pH's greater than 6. At pH 9, it is virtually unavailable. Soils high in organic matter, calcium, magnesium and phosphate may cause zinc to be unavailable to plants.



The potassium cycle is fairly simple. It is held in place by the cation exchange complex of the soil, and removed by vine roots. It is replaced in the soil by adding fertilizers, manures and composts.

### **Role and Utilization**

The precise role of potassium in grape vine physiology is not well known. The effect of deficiencies on vine growth and crop yields are better understood. Plants need potassium for the formation of sugars and starches, for the synthesis of proteins, and for cell division. Potassium also neutralizes organic acids, regulates the activity of other mineral nutrients in plants, activates certain enzymes, and helps to adjust water relationships. It is also involved in cold hardiness, and the formation of carbohydrates, even though it is not usually found as part of organic compounds. About 1 to 4 percent of plant tissue by weight is potassium.

The demand for potassium is highest during fruit ripening in mid to late summer when large amounts of the nutrient accumulate in fruit. Temporary deficiencies may be associated with overcropping.

### **Diagnosis of K Needs**

#### **Deficiency**

Recognizing deficiency symptoms is very important because response to potassium fertilizer usually occurs only when deficiency symptoms are present. Fertilizer trials conducted in vineyards with low but not deficient levels of potassium typically show no yield or growth response.

#### **Symptoms**

Leaf symptoms begin to show in early summer on leaves in the middle portions of the shoots. Marginal yellowing begins on the outer edge of the leaves. As the season progresses, the yellowing continues into the areas between the main veins, leaving a central island of green extending around the main veins. The yellowed areas of red colored grapes may bronze or redden. In all varieties, marginal burning and curling usually follows. Symptoms may develop in leaves above and below the middle of the stem right up until harvest time.

When potassium deficiency is severe, shoot growth is reduced, and symptoms may be visible before bloom. Fruit set often is poor, with small, tight clusters and unevenly colored small berries. Damaged root systems from high water tables in wet years, phylloxera and soil born plant disease may also cause vines to show potassium deficiencies. It is important to check root health whenever nutrient deficiencies are observed in a vineyard.

### **Suitability of Fertigation to Apply Potassium**

Because potassium is slowly mineralized in the soil and used in large quantities, fertigation alone may not be the best strategy to apply this nutrient. Soluble forms of potassium such as potassium nitrate, potassium thiosulfate, potassium phosphate and



Zinc deficiencies occur most frequently in vineyards planted on sandy soils, sites that were formally corrals or poultry houses, or places where land leveling has caused heavy cuts revealing subhorizons to the surface. Some vigorous rootstocks planted in these areas are prone to zinc deficiency, such as Dogridge, Salt Creek, Freedom and Couderc 1613.

Application of high nitrogen fertilizers may accentuate zinc deficiency, because nitrogen stimulates total vine growth and thereby increases the zinc needs beyond the available supply. Rapidly growing young vines sometimes exhibit temporary deficiency symptoms, but frequently grow out of it as their root systems expand and come into contact with larger soil surface area.

Zinc deficiency is very common following fumigation and planting. Like phosphorus, zinc uptake is probably dependant on mycorrhizal fungi populations, which assist roots in taking up selected nutrients.

### **Role and Utilization**

Zinc is critical for auxin formation, for the elongation of internodes and in the formation of chloroplasts and starch. In grapes, zinc is essential for normal leaf development, shoot elongation, pollen development and the set of fully developed berries.

### **Symptoms and Diagnosis of Deficiency**

Foliar symptoms vary depending on the severity of zinc deficiency. Foliar symptoms include mottling appearing in early summer at the time when lateral shoot growth is well developed. The new growth on both the primary and secondary shoots has smaller, somewhat distorted leaves, with a chlorotic pattern exposing the veins as a darker, green color. Even the smaller veinlets retain a uniform-width border of green unless the deficiency is quite severe.

Severely affected leaves have undeveloped basal lobes, and the sinus is shallow with little indentation where the petiole joins the leaf. "Little leaf" is a good description of the overall appearance of affected vines. Shoots are stunted, with closely spaced small, distorted leaves when deficiency is severe.

Fruit set can be seriously affected when zinc deficiency is severe. Clusters tend to be straggly with fewer berries than normal vines. Berry size varies greatly, with "pumpkin and pea" appearance. Uneven ripening is also noted. Some varieties like Muscat of Alexandria exhibit fruit symptoms without foliage symptoms. Others show both simultaneously.

Zinc deficiency symptoms are usually visually obvious, and tissue tests aren't needed to confirm them. Sometimes symptoms might be confused with other micronutrient deficiencies, or fanleaf virus. If there has been no history of zinc deficiency in the vineyard, and suddenly symptoms develop, it may be advisable to do tissue testing. Soil testing is not considered helpful, because it is difficult to correlate the zinc level in the



soil with that in the vine. Rootstocks have different abilities to forage for zinc, and may find adequate amounts even when the soil content is low.

### **Fertilization and Response to Zinc**

Zinc deficiencies are moderately easy to remedy and growers employ several different strategies to address the problem. Incorporating zinc sulfate preplant is recommended by many consultants, as zinc doesn't leach readily in the soil profile. Daubing concentrated zinc sulfate solutions on pruning cuts works for many cane pruned varieties. Prebloom foliar sprays with zinc sulfate can also be very effective. Soil applications can be effective on sandy soils. Zinc sulfate can be banded into the soil next to vines. Pressurized zinc sulfate solutions injected 18 inches into the soil can work well, particularly on young vines.

### **Suitability of Fertigation to Apply Zinc**

While zinc sulfate can be injected into irrigation water, it tends to stay on the surface of the soil when it reaches the vineyard. Chelated zinc can be applied through the irrigation system, and moves well through the soil into the root zone of the vines. Chelated zinc is about 5 times more expensive than zinc sulfate, but fertigation may still be cost effective due to potential labor savings and ease of application.

## **2. Boron**

### **Importance**

Boron is an important micronutrient for wine grapes. Boron is needed in very small quantities, and the range between deficiencies and toxicities is surprisingly small. One part per million of boron in the soil solution is sufficient, and several parts per million is probably toxic. Boron deficiencies occur in many parts of California. In the San Joaquin Valley, boron may be deficient in sandy soils formed as alluvium from granitic parent material, mostly on the eastern side of the valley. Irrigation water sources low in boron tend to leach this micronutrient from the soil profile. In Northern California, high rainfall tends to leach boron from the soil profile, and deficiencies are occasionally a problem. Toxicities are also a problem, coming from boron seeps that occur naturally, and from high boron content in irrigation water, both wells and surface water. There is no effective treatment for removing excess boron from irrigation sources.

### **Sources**

Boron occurs naturally in the form of borosilicate minerals which are resistant to weathering and release boron slowly. Much of the available boron is held by the organic and clay fractions in the soil in the anion exchange complex. Boron is less leachable than are other neutral or negatively charged plant nutrients.

Boron is also found occurring naturally in well water and surface water, particularly in the Coast Range. It is common in areas where there is geothermal activity.



### **Uptake, Utilization and Role**

Boron is taken up by plants as borate and is involved in the differentiation of new cells. When boron is deficient, cells may continue to divide but structural parts are not completely or properly formed. Boron also regulates carbohydrate metabolism. During bloom, low boron levels limit pollen germination, and normal pollen tube growth. This can result in poor pollination and fruit set.

Boron doesn't move from older tissues to new, and young leaves and shoots will show deficiency symptoms first. A continuous supply of boron is needed during the growing season for normal growth.

### **Diagnosis of Deficiency**

Boron deficiency symptoms can be very different and easily confused with other disorders. Two categories of deficiencies are recognized: a temporary, early spring deficiency, and early to mid summer deficiency.

Temporary early spring deficiency begins to appear after bud break. Stunted, distorted shoot growth characterizes the early growth, then most of the shoots begin to elongate normally as the season progresses. The shoots are dwarfed because internodes fail to elongate, and may grow in a zig zag manner. Numerous lateral shoots grow from the stunted shoots, giving the plant a bushy appearance. The growing tip may die on severely affected shoots; affected shoots are unfruitful or have undeveloped clusters. Often, these symptoms occur after a particularly dry fall and early winter and this type of boron deficiency is considered to be temporary.

The lower leaves on affected shoots are misshapen, but symptoms differ among varieties. For example, severely affected Grenach leaves are somewhat fan-shaped and may show an interveinal chlorosis; the serrations around the leaf edges are irregular, and the veins are more prominent than on normal leaves. Affected Chenin blanc leaves have a wide, fan shaped appearance and prominent veins. Barbera and Mission leaves have a more rounded but misshapen appearance.

Early to mid summer deficiency occurs more consistently from year to year than does early spring deficiency. Symptoms show right after flowering, and are most pronounced on berry set and growth. Low boron levels during the rapid growth rate before and after bloom cause the problem. The vine will have adequate boron levels later as growth slows into summer.

Fruit symptoms are the easiest to recognize. Severely affected vines may have no crop. Some clusters appear to burn off or dry up around bloom time, leaving only cluster stems, sometimes with occasional berries. Many clusters may set numerous small, seedless berries that persist and ripen. These clusters may be full or straggly and may also include some normal sized berries as well as shot berries. The shot berries are distinct and uniform in size and shape. Unlike the more oval or elongated normal berries of most varieties, the shot berries are very round, to somewhat flattened, resembling in profile a very small tomato or pumpkin. Shot berries caused by low boron levels should not be



confused with those caused by zinc deficiency. Clusters from zinc deficient vines have shot berries of normal shape typical of the varietal, and most of those berries remain hard and green. They are also more varied in size than those caused by boron deficiency. Occasionally, the clusters on boron deficient vines that appeared to set normally at bloom time will shatter severely in midsummer.

#### **Fertilization and Response to Boron**

Boron deficiencies are relatively easily corrected with applications of boric acid, solubor or borax applied to soil, usually mixed in with herbicides applied during the winter for beneath the vine weed control programs. Boron leaches readily through the soil, and is picked up the vine's root system.

#### **Suitability of Fertigation to Apply Boron**

Boron can be applied by fertigation through the drip system. Solubor, boric acid and borax are all forms that are used that are sufficiently soluble and effective as fertilizers.

### ***3. Iron***

#### **Importance**

Iron is considered the third most common micronutrient deficiency in California, behind zinc and boron. Fortunately, most iron deficiencies are temporary and isolated. Symptoms are most likely to occur when vines are planted on soils containing high levels of limestone, or having either high or low pH. Iron deficiencies might also be noted on vines with weakened root systems, or when vines have been over cropped in previous seasons, and the available iron in the soil is limited.

#### **Soil Availability and Uptake**

Iron occurs in soils as oxides, hydroxides and phosphates, as well as in the lattice structure of clay minerals and some silicates. As an element, it is abundant in soil. Under varying soil conditions, small amounts of iron are released during the weathering of these minerals, and are absorbed by roots in the ionic form or as complex organic salts. In the ionic form, iron is highly reactive and easily oxidized, and is present in the soil solution in very small amounts.

Deficiency symptoms occur primarily when soil conditions limit root uptake and vine utilization of iron rather than total iron in the soil. In California, high pH soils that are either affected by high phosphate, high lime (calcium carbonate) content, or high alkali (saline-sodic) content are most likely to show iron deficiencies. In these soils, a condition known as "lime-induced iron chlorosis" occurs, in which iron is immobilized or inactivated by the high levels of carbonates or lime in the soil.

Vines growing in fine textured soils, especially when poorly drained and cold, are more likely to show iron deficiency symptoms if saline-sodic or high lime content conditions are also present. Iron deficiency is often noted in the spring when weather is cool and wet, and frequently, vines grow out of the problem as the weather warms. However, vines can also show symptoms during periods of rapid growth and warm temperatures.



### **Utilization and Role**

Iron is transported in plants as the ferrous ion ( $\text{Fe}^{++}$ ), and becomes immobile as it is complexed into various organic compounds. Iron isn't transported readily in the plant from one tissue to another, and new growth is most likely to show deficiency symptoms.

Iron functions in the activation of several enzyme systems. A shortage of usable iron also impairs chlorophyll production, resulting in the characteristic chlorosis.

### **Diagnosis of Deficiency**

Foliar symptoms first appear as interveinal yellowing on shoot tip foliage. As the leaves expand, the blade appears pale yellow with clearly defined green veins (as opposed to zinc deficiency, in which the green pattern is more diffuse). As deficiencies worsen, the leaves may become ivory or white, and even brown and necrotic. Growth is reduced on severely affected shoots, and cluster rachis is likely to be chlorotic. Fruit set is likely to be poor on affected shoots.

As grapevines recover from temporary deficiencies, the new growth develops with a normal green color. Color improvement is delayed on mature leaves affected earlier in the season.

Soil and tissue analysis have not been found to be useful in diagnosis, because soil and plant tissue iron levels do not necessarily correspond to the occurrence of deficiency.

### **Correcting Deficiency Symptoms**

Iron deficiency is considered to be one of the most difficult nutritional problems to correct in plants, and grapevines are no exception. Foliar applied iron solutions have only limited success, as grape vine leaves do not absorb or translocate these materials very well. Soil applied iron sulfate or other inorganic compounds do not move through the soil very well, and are rapidly inactivated by oxidation and complexing under high lime or saline-sodic soil conditions. Iron chelates (such as Fe-EDDHA or Fe-DTPA) work better, but are quite expensive, and the effects are not always long lived. More successful approaches would involve applying soil amendments such as sulfur, gypsum or sulfuric acid to improve the rooting environment in the soil. Sulfuric acid is sometimes used to condition both water and soil as a way of lowering pH and improving the rooting environment in saline-sodic or high lime content soils. Other crops have also used urea sulfuric acid (N-pHURIC) to improve soil conditions and apply nitrogen at the same time.

If an area is chronically affected, lime tolerant rootstocks can be considered for use. In Europe, the rootstocks Fercal and 41-B are widely used in soils with large amounts of active lime. Unfortunately, little is known about the performance of these rootstocks under California conditions.

### **Suitability of Fertigation to Apply Iron**

Iron chelates will dissolve readily in water, and can be easily applied to grapevines through a microirrigation system. This is an expensive treatment, and won't be effective



long term unless soil conditions are also addressed. Injections of sulfuric acid or urea sulphuric acid are also possible, but require caution and special attention to protecting the operators, the irrigation system, and the environment, as these materials can be quite corrosive. Inorganic salts of iron are not usually effective when applied to the soil surface under high pH conditions.

#### **4. Manganese**

##### **Importance**

Manganese deficiency is not common in California vineyards and is rarely severe. It occurs most often in sandy soils. Toxicities are sometimes a problem in serpentine soils. High manganese levels may interfere with iron availability and uptake by plants.

##### **Sources in the Soil**

Soil manganese originates from the decomposition of ferro-magnesian rocks. Manganese occurs as both an oxide and an ion in the soil solution, which is absorbed and exchanged in soil colloids and organic matter. Soil pH influences availability, with increases as the soil becomes more acidic (lower pH).

Manganese is often supplied to plants when the soil becomes temporarily anaerobic following irrigation or rain. The temporary lack of oxygen causes manganese oxides to dissolve slowly. The small amount of manganese that does dissolve is often available for several days after anaerobic conditions. Consequently, manganese deficiencies are not common unless the soil is naturally low in manganese containing compounds.

##### **Utilization and Role**

Plants take up manganese in the ionic form ( $Mn^{++}$ ). It is a relatively immobile nutrient within the plant. Manganese serves as an activator for enzymes in growth processes. It assists in chlorophyll formation, and leaf chlorosis is an early deficiency symptom.

##### **Diagnosis of Deficiency**

Symptoms can appear in two or three weeks after bloom on severely deficient vines. A mild to moderate deficiency will not appear until midsummer to late summer. The symptoms begin on the basal leaves as a chlorosis between the veins. Increasing chlorosis develops between the primary and secondary veins; the veinlets tend to retain a green border. Thus, a somewhat distinct herringbone chlorosis pattern can ultimately develop on manganese deficient leaves. These symptoms should be distinguished from those of zinc, iron and magnesium deficiencies. Zinc deficiency symptoms first appear on newer growth and include some leaf malformation. Iron deficiency also appears on newer growth and causes a much finer network of green veins in the yellowing leaf tissue. As with manganese deficiency, magnesium deficiency chlorosis first appears on the basal leaves, but it is more extensive between the primary and secondary veins, developing into more complete yellowish bands, lacking the herringbone pattern. Laboratory analysis of petiole samples from affected leaves and from normal leaves should be used for the final diagnosis.



### Correction of Symptoms

Deficiencies in California are considered rare and inconsequential. Most occur on older leaves late in the season, and this minimally affects vine physiology and fruit ripening. Little trial work has been done on manganese deficiencies in California. Foliar sprays of either manganese sulfate or chelated manganese have been used with some success by growers.

### Suitability of Fertigation To Apply Manganese

It is unlikely that it would be necessary to apply manganese to a vineyard in California. Manganese is not well bound by chelates, and tends to drop off chelation molecules when applied to the soil. Often iron is substituted instead, and picked up by roots with the chelating agent. This results in an imbalance which might actually accentuate the manganese deficiency. Consequently, should manganese be deficient, it is more effective to apply inorganic forms of this element (such as manganese oxides, hydroxides, carbonates or sulfates) by broadcasting and incorporating them into the soil. Fertigation would not be recommended as a way to alleviate a manganese deficiency.

**Table 1: Summary of Grape Vine Nutrient Deficiency and Treatment**

Element	Seasonal Appearance	Shoot Position	Common?	Appropriate for Fertigation?	Easily Corrected?
Boron	Early	Apical	Yes	Yes	Yes
Zinc	Early	Apical—mid stem	Somewhat	Somewhat	No
Iron	Early	Apical – entire	No	Somewhat	No
Manganese	Mid	Basal	No	No	No
Phosphorus	Mid	Basal	No	Yes	Somewhat
Potassium	Mid-late	Mid	Yes	Yes	Yes
Magnesium	Late	Late	No	Yes	Yes
Nitrogen	Not diagnostic		Yes	Yes	Yes



## **C. Determining Nutrient Status**

### ***1. Soil Testing***

#### **Before Vineyard Establishment**

Soil testing is essential before establishing a vineyard to determine solutions to many design issues. It is well worth the money to have a trained soil scientist assist you in assessing the soils of a proposed vineyard site. Soils need to be examined for both their chemical and physical properties in order to determine if the site is a good choice for the varietal that you wish to grow. This information will also be necessary to choose rootstocks, select a trellis system, design and lay out the irrigation system, and determine if drainage is going to be needed for the vineyard.

Soil pits dug with a back hoe are the best way to examine a soil profile. Pits should be dug in all representative soil types in the proposed vineyard area. Soils maps provided by the USDA Natural Resource Conservation Service provide an excellent starting point to determine what soils are most likely present on the site. Most soil consultants feel that there should be one pit for a minimum of five acres. Smaller areas that have very different textures should also be examined. Soil pits are normally about 6 feet deep. For each pit, a description of the soil profile is developed, noting abrupt changes in texture, any barriers to root penetration, signs of high water tables or anything else that would affect vine rooting. Samples from the different horizons are then taken, either by the distance from the surface (1-6 inches, 7-12 inches, etc.) or by the horizon, if soil textures are very different with depth in the pit. Typically, field notes include information on soil structure, color, presence or absence of roots, texture (determined by feel) and notes about the composition of the different horizons.

If the soil in the area to be developed has already been well characterized, and you wish only to test the upper 12 to 18 inches of soil, a simpler sampling technique can be used. Choose a uniform area to sample, preferably by soil type, representing 10 acres or less. Avoid sampling from spots that are clearly inconsistent with the main area being sampled. For each horizon that you are going to sample, carry a five gallon bucket for mixing subsamples. Select 25 to 50 spots chosen randomly, preferably sampled diagonally across the area. Scrape off the upper one inch of soil, removing and plant or crop residues. Using either a shovel, garden trowel, auger or a soil probe, sample the soil by increments of 6 inches into the soil profile. Depending on the level of detail that you want, you can combine the depths, although the soil generally changes substantially below 12 inches. When you have finished taking the subsamples, thoroughly mix them for each horizon that you want analyzed; i.e., 1-6 inches 7- 12 inches, and 13-18 inches. Take a quart volume of dry soil, and put into a properly labeled container with information that includes the location, depth of sample, and date sampled. If you want to have nitrogen analyzed in the soil, you need to keep the samples cool and deliver them rapidly to the lab, as nitrogen is not stable in the soil. Otherwise, storage is not so critical for other analyses.



If you are checking for the results of your fertigation practices, you may wish to only sample the areas beneath the drip emitters. It will give you the most accurate information about the outcome of nutrient delivery to the soil.

Standard laboratory analysis will include chemical properties: nutrients, pH, electroconductivity (salinity), cation exchange capacity and base saturation. Physical properties tested will include saturation percentage, and soil texture. If the vineyard is in an area prone to salinity problems, it is advisable to also have the soils tested for sodium adsorption ratio, exchangeable sodium percentage, carbonates and residual bicarbonates. This information will be needed for long term irrigation management. Grapevines are sensitive to high levels of soluble salts in both water and soil. Sodium, chloride, and boron are toxic to vines at levels that do not affect other crops, such as cotton and alfalfa. Vine growth and production can be severely restricted when vineyards are planted on soils high in soluble salts (saline soil), or adsorbed sodium (sodic or alkali soils) or both (saline-sodic). An excellent reference is available: *Salinity Appraisal of Soil and Water for Successful Production of Grapes* (University of California DANR Leaflet 21056) Following are brief guidelines for interpreting soil reports:

**Saturation Percentage (SP):** This measurement is a quick way to estimate soil texture, water holding capacity and cation exchange capacity. It is expressed in grams of water required to saturate 100 grams of soil. The following table shows the relationships between different SP's.

**Table 2. Relationship of Saturation Percentage to Soil Texture, Cation Exchange Capacity (CEC) and Available Water (Field Capacity- Permanent Wilting Point)**

Saturation %	Soil Texture	CEC (meq/ 100g of soil)	Available Water (in. /ft)	Potential Grape Vine Vigor*
Below 20	Sandy or sandy loam	2-7	<0.6	Very low
20-35	Sandy loam	7-15	0.6-1.0	Low-moderate
35-50	Loam or silt loam	15-30	30-40	Moderate to high
50-65	Clay loam	30-40	1.5-2.0	High to very high
65+	Clay or peat	>40	>2.0	Very high to extremely high

\*based on four foot of rooting depth with no chemical or physical rooting limitations

**Soil Reaction or pH:** This is a measurement of whether the soil is acidic (pH 3-6.9), neutral (pH 7.0) or alkaline (pH 7-9+). Grape vines tolerate a wide pH range, but they grow especially well in the range of pH 6.5 to 7.5. Depending on the concentration of base ions (Na, Ca, Mg, K) present in the cation exchange complex, it may be necessary to add amendments to soil to correct the pH. Lime (calcium carbonate) is used to raise the pH, and gypsum (calcium sulfate) or sulfur (elemental sulfur) are used to lower the pH.

#### **Saline Conditions:**

Under arid conditions, some soils are naturally saline (salty). To complicate the situation, dissolved salts in irrigation water remain in the soil after plants extract the water, or the water evaporates. For healthy plant growth, the salts must be removed by applying extra water during irrigation to leach the salts below the root zone. For this to work, the soil



must either drain well naturally, or drainage must be provided, with a place for the leachate to drain to.

To measure soil salinity in the laboratory, a saturation extract is made by mixing soil with distilled water. Soil water is then vacuum extracted and the extract is analyzed for water-soluble salts: sodium ( $\text{Na}^+$ ), calcium and magnesium ( $\text{Ca}^{++}$   $\text{Mg}^{++}$ ), chloride ( $\text{Cl}^-$ ), carbonate plus bicarbonate ( $\text{CO}_3^{--}$  and  $\text{HCO}_3^-$ ), sulfate ( $\text{SO}_4^{--}$ ), boron ( $\text{B}^-$ ) and nitrate nitrogen ( $\text{NO}_3^-$  N). The electroconductivity (EC) of the soil extract is a measurement of total dissolved salts in the solution.

By definition, a saline soil has an EC of the soil extract greater than 4 mmhos/cm (at 25 degrees C). In water, 1 mmho/cm of electrical conductance is approximately 640 ppm (1700 lbs of salt per acre foot). Vines do best when the soil EC is less than 1.5 mmhos/cm in the root zone (to a depth of 3 –4 feet.) Yields and vine growth are substantially reduced as EC increases above 2.5 mmhos/cm. The primary effect of total salinity is a reduction of water availability to roots through osmotic effects. Adding fertilizers to the soil or irrigation water is going to increase the salt load to the vineyard.

Vineyards are usually planted in well drained soils and are irrigated with good quality water. Winter rainfall is usually adequate to leach salts through the soil profile. If soil analysis indicates excess salts, additional irrigations in late fall or spring made be needed to leach the salts through the root zone.

The amount of extra water needed to leach salts through the soil profile depends on the initial soil salinity level, the technique of applying water, and the soil type. A general rule of thumb is that 1 foot of extra water will remove 70-80 percent of excess salinity in the upper foot of the soil profile. Leaching this amount of salts is dependant on good drainage.

#### **Sodic (Alkalai) Soils:**

Soils that contain excessive amounts of exchangeable sodium ( $\text{Na}^+$ ) in proportion to calcium ( $\text{Ca}^{++}$ ) and magnesium ( $\text{Mg}^{++}$ ) are termed sodic or alkali soils. Sodic soils are characterized by dispersed soil particles that reduce both water and air permeability.

By definition, a sodic soil has an exchangeable sodium percentage (ESP) greater than 15. That is, 15 percent of the soils cation exchange capacity is filled with sodium and the remainder with calcium, magnesium, and other cations. Grapevines are very sensitive to sodium and its accompanying effect on soil permeability and aeration. Toxicity symptoms can appear in grapevines before significant loss of water permeability in the soil occurs. For grape vines, ESP in the root zone greater than 10 will cause toxicity symptoms.

When sodic soil conditions are identified, laboratory analysis can be performed to determine the amount of gypsum needed to help alleviate the effects of a high ESP. After application of gypsum, extra irrigations are needed to leach sodium out of the soil, usually applied during the vineyard's dormant season. Organic matter inputs into the soil



in the form of cover crops or other crop residues, compost and composted manures, can also help lessen the effects of sodic soil conditions. Decomposed organic matter can adsorb some of the salts, and organic glues and exudates from microorganisms living in the soil help to restructure soil aggregates, improving water and air infiltration.

**Table 3: Guidelines for Interpreting Laboratory Data on Soil Suitability for Grape Vines**

Possible Problem and Unit of Measurement	No Problem (less than 10% yield loss expected)	Increasing Problems (10 to 25% yield loss expected)	Severe Problems (25 to 50% yield loss expected)
<b>Salinity</b> E <sub>cw</sub> mmhos/cm	1.5 to 2.5	2.5 to 4	4 to 7
<b>Permeability</b> ESP	Below 10	10 to 15	Above 15
<b>Toxicity</b> Chloride meq/l (mg/l or ppm)	Below 10 (350)	10 to 30 (350 to 1060)	Above 30 (1060)
Boron mg/l or ppm	Below 1	1 to 3	Above 3
Sodium (meq/l) (mg/l or ppm)		Above 30 690	
<b>Miscellaneous</b> pH	5.5-8.5		

#### **After Vineyard Establishment**

Once the vineyard has been planted, soil testing alone will not give an accurate view of vine nutrient status. Tissue testing is a more effective way to determine what the grape vines are actually utilizing in the soil. Periodic soil testing is advisable if you are applying soil amendments to address pH or salinity problems, or problem spots in the vineyard where vine performance is poor. 1

## **2. Water Testing**

Water testing needs to be done prior to vineyard planting to be certain that the water is suitable for irrigation. If an irrigation district is supplying water for your farm, they may already have water quality information available. If you are sampling well or pond water on your property, allow the pump that provides water for your irrigation system to run for 20 or 30 minutes before sampling to insure that you are getting a representative sample. Put the sample in a clean, labeled container that is chemically stable. If you are



sampling for nitrogen or bacteria, you will want to keep the sample cool and deliver it to the laboratory as soon as possible.

### **Sodium Hazard in Water**

There is a close association between the composition and concentration of salts in irrigation water and those in the soil. When used for irrigation, waters with high sodium relative to calcium and magnesium are likely to result in a sodic soil. Water's sodium hazard is evaluated by the sodium adsorption ratio (SAR):

$$SAR = \frac{Na}{\sqrt{Ca + Mg}}$$

NOTE: FORMULA NEEDS FIXING

Carbonate ( $CO_3^{2-}$ ) and bicarbonate ( $HCO_3^-$ ) can aggravate an Na hazard by precipitating some of the exchangeable calcium and magnesium. The adjusted SAR (adj SAR) accounts for this; laboratories often report SAR and adj. SAR.

Waters with low adj.SAR dissolve lime from the soil and increase exchangeable calcium. Waters with high adj. SAR cause calcium to precipitate and decrease exchangeable calcium and can lead to sodic conditions. Irrigation waters with adj. SAR values below 6 are preferable; when values exceed 9, problems can occur.

Gypsum should be used to replace precipitated calcium when using water with a high adj.SAR. It is normally applied to the bottom of furrows or that portion of the soil surface wetted by irrigation water. Two tons of gypsum per acre every year or so is a common rate; incorporation is not necessary.

### **Slow Infiltration associated with High-Purity Water**

Irrigating with very pure water on slightly salty soils may slow infiltration into sandy loam or finer textured soils. It is a common problem on the San Joaquin Valley's east side where the primary irrigation source is canal water originating as snowmelt from the Sierra Nevada Mountains and containing only 50 to 100 ppm salts. With certain soils water infiltration can drop to less than 0.1 inches per hour, making it difficult to satisfy the vineyards water requirements.

Application of gypsum can help fix water penetration problems created by using pure irrigation water. The water infiltration rate can be increased up to five fold by applying 1 or 2 tons of gypsum per acre in late spring or in early summer, just before peak vineyard water demand. Gypsum is generally beneficial for three to five irrigations. Infiltration can also be improved by applying gypsum directly to the irrigation water at a rate of 300 to 500 lbs per acre foot. Specialized equipment is required to apply gypsum into water. Smaller amounts of gypsum are required when applied with water. Many soil consultants believe that injection needs to occur with each irrigation for this to be effective, as the soil will seal up again if injections aren't continued.



### **Toxicity Caused by Excess Boron, Chloride and Sodium**

Grapevines are sensitive to sodium and chloride. Accumulation of sodium or chloride ions in leaves may impair leaf stomatal closure and reduce vine growth. Marginal leaf burn strongly indicates toxicity caused by high levels of sodium, chloride or both. Leaf analysis is the most useful tool in diagnosing salt injury to vines; however, soil and water analysis may be needed to complete the diagnosis in an established vineyard. Both soil and water analysis are essential when determining the suitability of a vineyard site, especially in areas where sodium, chloride and boron levels are known or suspected to be high.

Problems with chloride toxicity often occur in vineyards planted on saline soils that have not been fully reclaimed and/or when high chloride irrigation water is used. It is much more difficult to correct a salinity problem after the vineyard is planted, underscoring the importance for complete reclamation before planting.

Occasionally, chloride toxicity to grapevines occurs following applications of fertilizers containing chloride, such as muriate of potash (potassium chloride) on poorly drained soils. The problem can be easily corrected by leaching excess chloride from the root zone; nevertheless, use fertilizers containing chloride cautiously. Don't use chloride containing fertilizers on poorly drained soils. If possible, make applications in the fall, allowing winter rains to leach the chloride before bud break.

Boron interferes with chlorophyll synthesis and is toxic at levels only slightly greater than required for nutritional purposes. Toxicity is common where soils are derived from marine sedimentary material, with both soil and groundwater likely to contain high levels of water. It is also associated with geothermal activity in ground water.

Soil and water analysis can help indicate a potential boron hazard. Soil samples should be taken to 5 feet as boron levels are often higher in the subsurface. Irrigation water should not exceed 1 ppm or toxicity problems are likely to develop. The only reclamation procedure is leaching the affected soils with water, which can be a slow and difficult process.

### **Nitrogen in Well Water**

Nitrate nitrogen ( $\text{NO}_3^-$ ) in groundwater can contribute significant amounts of nitrogen towards a grapevine's nutritional needs and should be considered when planning a fertilizer program. In some areas, nitrogen levels in irrigation water often range from 5 to 50 pounds of nitrogen per acre foot. Laboratories report  $\text{NO}_3\text{-N}$  concentrations in ppm. To convert to pounds of nitrogen per acre foot, multiply by 2.7. Excessive amounts of nitrogen might unintentionally be applied just with normal irrigation, so it is worth knowing about before the vineyard is planted.

### **Testing for Potential Chemical Precipitate Clogging**

Some fertilizers may have a tendency to clog emitters if a chemical reaction between the injected material and irrigation water results in a chemical precipitate. There are three common situations where this can occur. The first is when the injected material contains



calcium (such as calcium nitrate or soluble gypsum), which may combine with the water's natural bicarbonates and precipitate as calcium carbonate (lime). The second is when the injected material increases the pH of the irrigation water above 7.5, which increases the likelihood that calcium carbonate in the irrigation water may be precipitated. The third is when phosphorus-containing fertilizers are injected into high-calcium irrigation water, resulting in calcium phosphate precipitate.

Because there are numerous other instances where injected materials may result in chemical precipitates, a wise precaution is to do a "jar test" before anything new is injected into the microirrigation system. To do a jar test, add the material to be injected to the irrigation water in approximately the concentration at which it will be injected: shake the jar (preferably a clear glass jar) to mix the solution; and let it sit for a few hours. If any precipitate appears, do not inject the material. You may ultimately be able to inject the material if you can adjust the pH of the irrigation water to keep the precipitation from occurring. This usually requires adding acid to the irrigation water to lower the water pH. Very low water pH (less than 4.5) should be avoided since it may damage metal fittings and other system components.

### **Iron and Manganese**

Iron and manganese are sometimes found in well water, and very low amounts (less than 0.2 ppm) can be sufficient to cause bacteria to grow in the irrigation system. These bacteria oxidize iron or manganese from the irrigation water as an energy source. Dissolved iron is not considered to be toxic to plants. Dissolved manganese can be toxic but fortunately is not common. There are various types of bacterial strains that feed on these elements, and form long slimy sheath-like strands of growth that can completely clog an irrigation system in less than a month. Iron bacteria is reddish in color, and manganese bacteria tends to be blackish in color.

Water treatment to control the bacteria is difficult, because often the well is contaminated and continues to introduce the bacteria to the well. In severe cases, it is advisable to build a pond or a holding tank where the well water can be aerated, which causes the iron or manganese to precipitate and fall out of the water. The water can then be used in the irrigation system with minimal problems. Chlorine injections into the irrigation system are quite effective as well as polymers that sequester the iron and manganese, keeping these metals suspended in the water (see also *Flushing and Chlorination*).

### **Iron and Manganese Sulfides**

Dissolved iron and manganese in the presence of sulfides can cause a black, insoluble precipitate to form in the irrigation system. If a combination of greater than 0.6 ppm iron and greater than 2.0 ppm sulfides is found in the water, it is likely that a black sludge caused by iron sulfide will form. Manganese is more likely to damage crops before forming bacterial sludge, because it is toxic at fairly low concentrations. This problem is found almost exclusively in well water, because the dissolved chemicals precipitate readily when exposed to the atmosphere. Consequently, aeration is the best treatment for this problem. It may also be necessary to acidify and chlorinate the water if bacteria continues to cause clogging (see also *Flushing and Chlorination*).



**Table 4: Guidelines for Interpreting Laboratory Data on Water Suitability for Grape Vines**

Potential Problem	No Problem	Increasing Problem	Severe Problem
<b>Salinity</b> -affects water availability to crop Ecw (mmhos/cm)	<1	1.0 to 2.7	>2.7
<b>Permeability</b> -affects rate of water movement into and through the soil EC w (mmhos/cm)	>.5	0.5 to 0.2	<0.2
Adj. SAR (an estimate of the permeability hazard)	<6		>9
<b>Toxicity of Specific Ions</b> affecting plant growth			
Sodium (meq/l)	<20		
Chloride (meq/l)	<4	4 to 15	>15
Boron (ppm)	<1	1 to 3	>3
Manganese (ppm)			
<b>Miscellaneous</b>		1.5 to 7.5	
Bicarbonate	<1.5		>7.5
Nitrate-nitrogen (ppm)	<5	>6 to 30	>30
Iron (ppm)-clogging	<0.2	>0.2	
Manganese (ppm)-clogging			
Sulfides(ppm)-clogging*	<2.0	>2.0	

\*Iron or manganese must also be present to be a problem in concentrations >0.6 ppm

### 3. Tissue Testing

Plant tissue analysis is considered the best method for determining vine nutrient status. Petioles (the stem of the leaf) are sampled opposite grape flowers in full bloom (when approximately two-thirds of the caps have fallen from the flowers). Around the state, this may be any time from early May to mid June, depending on the location, varietal and season. Petioles are separated from leaf blades, placed in small paper bags, and immediately sent for analysis to a qualified lab.



### **Vineyard Sampling**

Petiole samples should be taken from only one varietal, and from areas no larger than 10 acres. If there are different soils in the block, and vines are growing differently within the block, take more samples from the areas where vines are growing differently.

Usually, 75 to 100 petioles gathered randomly from across the vineyard block is an adequate sample. *Remember, if you have applied pre-bloom sprays, it will give you incorrect readings, and will probably overstate the actual nutrient content of the sample. Don't sample from treated blocks, or thoroughly wash the petioles after sampling to dissolve any fertilizer on the tissue surface.*

Growers who routinely sample vineyard blocks from year to year may wish to designate specific rows or vines in a representative area. Resampling the same vines each time improves consistency in the results when tracking the vineyards' nutrient status and adjusting the fertilizer program over time.

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Samples should be placed in clean paper bags that are labeled with the vineyard name, date, varietal, and any other important information. Deliver to the laboratory immediately, if possible. Otherwise, dry the samples in an oven at a low temperature to prevent mold from occurring. Leaving the petioles in your vehicle for a few days, if the weather is warm, is also another way to safely dry the samples.

### **Follow-up Nutrient Sampling**

If the results of your bloom sample indicate a potential deficiency, you can resample the block later in the season to determine if a deficiency has developed. This is particularly useful for potassium levels, which decline in the vegetative parts and can become deficient during fruit ripening. Sampling should be done at veraison, when the fruit softens or turns color at the beginning of ripening. This is another physiological stage when leaf tissue is still healthy and functioning, and for some varieties, there are supportive data. Select petioles from recently matured leaves. This should be the second fully expanded leaf, usually the 6<sup>th</sup> or 7<sup>th</sup> one from the shoot tip on actively growing shoots. The sample leaves should have the color and texture of the other mature leaves rather than the lighter and more shiny, tender appearance of young, expanding leaves. Because the leaves tend to be smaller than those sampled at bloom time, you may need to sample more petioles (75-100) to insure that you have an adequate sample size. If you are sampling leaf blades, 25 to 35 are sufficient due to their greater mass as compared to petioles.

### **Interpretation of Laboratory Analysis**

The following interpretations in Table 5 give critical values for important grapevine nutritional elements in petioles opposite flower clusters at bloom unless otherwise noted. The deficiency level is that at which deficiency symptoms may develop and/or a measurable response to fertilization with the nutrient in question can be expected.



**Table 5. Interpretive Guide for Grape Tissue Analysis at Bloom and Veraison**

Nutrient	Deficient (below)	Adequate (above)	Excessive <sup>2</sup> (above)	Toxic <sup>3</sup> (above)
NO3-N, ppm	350 <sup>1</sup>	500	2,000	8,000
P(total)%	0.10 (0.8) <sup>4</sup>	0.15 (0.12) <sup>4</sup>		
K(total)%	1.0 (0.5) <sup>4</sup>	1.5 (0.8) <sup>4</sup>		
Mg (total), %	0.2	0.3		
Zn (total), ppm	15	26		
Mn (total),ppm	20	25	300	1200
B (total), ppm	25	30	100	150 300 in blades
Na (total), %				0.5 0.3 in blades
Cl (total), %			0.5-1.0	1.5 0.5 in blades

1. Critical NO3-N levels are based on Thompson Seedless Data Only. Some labs report as % NO3. Multiply %NO3 by 2258 for ppm NO3-N (i.e. 1% NO3 = 2258 ppm NO3-N)
2. Excessive levels may be cautionary rather than indicating known effects on vine performance
3. Critical toxicity values are not well defined due to variety, growing condition and seasonal differences
4. Veraison (berry softening) petiole values are in parenthesis

### **Nitrate-Nitrogen (NO3-N)**

Critical levels of nitrate-nitrogen have only been established for Thompson Seedless grapes. Interpreting nitrate-nitrogen levels in grape vines can be difficult, as the levels are variable based on varietal, rootstock, weather during sampling and rainfall. Grape varieties differ greatly in their nitrate-nitrogen levels due partially to their differences in nitrogen metabolism. There are differences between varieties in the amount of the enzyme nitrate reductase. Nitrate reductase is an important in NO3 reduction, the first step toward conversion to other nitrogen compounds. Low levels of this enzyme means higher levels of nitrate-nitrogen are present in samples. Following is a chart of that shows the range of nitrate levels of different varieties:



**Table 6: Ranking of Grape Varietals by Their Comparative Bloomtime Petiole NO<sub>3</sub>-N Levels When Grown on their Own Roots**

High	High- Medium	Medium	Low-Medium	Low
Malbec Merlot Grenache  Tinta Madeira White Reisling Sauvignon blanc Black Corinth Redglobe	Petite Sirah Chenin blanc Muscat of Alexandria Emperor Christmas Rose	Pinot noir Semillon Cabernet sauvignon Rubired Chardonnay Zinfandel Carignane Thompson Seedless Ruby Seedless Calmeira Exotic	Barbera French Columbard Gewurtztraminer  Tokay	Slyvaner Salvador Ribier  Flame Seedless Perlette

Based on data of L.P. Christensen, W.M. Kliever, and J.A. Cook, UC Davis

Seasonal changes in nitrate nitrogen levels can be rapid, especially with extreme weather changes before bloom. Increases are associated with cool temperatures and low light intensity while sunny, warm weather favors decreased levels. They are typically highest 5-10 days before bloom, decline through the bloom period, and reach a relatively stable, lower level by 2 to 3 weeks after bloom.

Rootstock choices can also strongly affect N uptake. Higher petiole values are commonly experienced with Freedom, Ramsey (Salt Creek), St. George and 3309. Lower values are more common with 5C, 420 A, Harmony and 110R. Not all varietals have been investigated, but N levels in Flame Seedless, Merlot and Pinot noir are known to be strongly influenced by the choice of rootstocks.

Critical levels of total N analysis have not been established due to the relatively small differences in tissue levels between vines responding to N fertilization. This is apparently due to the masking effects of the large amount of protein N which make up the leaf tissues as compared to the assimilable N forms, including NO<sub>3</sub>-N. However, there is interest in using total N values due to the problems of seasonal, regional and varietal variability of NO<sub>3</sub>-N. Sources in foreign literature suggest critical deficiency values of <0.5 and <1.5% total N in bloom petioles and planes, respectively. These values should be used with caution, as they are not based on California data and experience.

Remember, the final criteria in N fertilization in assessment of vine canopy and rate of growth. Highly vigorous vines do not need N regardless of tissue levels.

### **Phosphorus**

Confirmed phosphorus deficiencies are rare in California, although they may occur in some coastal or foothills sites, especially on soils that are strongly acidic or high in iron. Petiole phosphorus levels tend to decline through the bloom period and level off through midsummer, so phosphorus levels in tissue can change during the season. Differences



among leaf petioles along the shoot are minor. Levels in the same vineyard can fluctuate as much as 100% from year to year.

Rootstocks can also influence phosphorus uptake. Rootstocks which tend to increase phosphorus levels include Ramsey, 110R, 1103P, and St. George. Rootstocks associated with lower phosphorus levels include 039-16, 3309C, 420A, 101-14Mgt, and Harmony.

### **Potassium**

Tissue analysis will confirm deficiency symptoms and is particularly useful in identifying isolated areas which warrant treatment. Vines in the questionable range at bloom should be rechecked 6-10 weeks later at veraison by sampling recently mature leaf petioles. This will determine if deficiency is developing at fruit ripening, a more common occurrence.

Petiole potassium levels usually decline most rapidly from before bloom until 2 to 4 weeks afterwards. Thereafter, they decline gradually or level off through midsummer. Heavy crop loads can lower petiole K levels dramatically during fruit ripening. Harvest-time levels associated with deficiency symptoms are 0.3% and below. At harvest, 0.5% is the critical level.

Potassium levels are the highest in the youngest mature leaf petioles where they peak at bloom and then decline with time and leaf age. Potassium levels can vary widely (30-50%) from year to year in the same vineyard and are strongly affected by varietal, rootstock and irrigation practices.

Rootstocks which tend to raise potassium levels include Freedom, Harmony, St. George, and 039-16. Rootstocks associated with lower potassium levels include 420A, 110R, 5BB, 3309C, and 140Ru. These differences may be affecting fruit pH as well as vine susceptibility to K deficiency.

### **Magnesium**

Petiole levels increase as the growing season progresses and tend to be higher in older petioles. Critical levels are probably higher later in the season, but they have not been established. For example, mild deficiencies may occur in the late season with levels of 0.5% magnesium or more. Magnesium tends to be reciprocal to potassium in tissue concentration, a relationship that is strongly influenced by varietal and rootstock, as well as soil levels. Ratios of potassium: magnesium under deficiency situations vary too widely to be diagnostic. However they can be indicative of extremes where antagonism may contribute to either magnesium or potassium deficiency. For example, magnesium deficiency is more commonly associated with potassium: magnesium ratios of >10:1 with petiole magnesium deficiencies at <0.2%. Potassium deficiencies are more commonly noted in serpentine soils with large amounts of magnesium where petiole levels at bloom may be above 3.0% magnesium and corresponding low levels of potassium. Even so, the absolute levels of magnesium and potassium, rather than their ratios, are the most definitive indication of a deficiency.



### **Calcium**

Critical tissue levels are not identified, as calcium deficiency has not been documented in California. The benefits of calcium in amending sodic (high sodium) or high acid soils are well known, but this practice is directed at soil management rather than vine nutrition. Direct vine response to calcium has only been demonstrated under extremely high magnesium level conditions, presumably due to magnesium antagonism to calcium and potassium uptake. Normal petiole levels begin at around 0.5% calcium, most commonly range from 1.0 to 2.0%, and can occur about 3.5% in petioles where magnesium and potassium levels are low.

### **Zinc**

Grape varieties and rootstocks vary widely in susceptibility to zinc deficiency. Most varieties fit with the critical levels given, although sensitive varieties such as Merlot, Ribier, and Muscat of Alexandria should always be maintained above the adequate threshold level. Low susceptible varieties such as Perlette and Chenin blanc will tolerate levels at or slightly below the deficient level of 15 ppm Zn. Differences in petiole levels along the shoot and changes during the growing season are minor. Bloomtime levels are most critical because of possible fruit set and “shot berry” effects.

### **Manganese**

California experience with deficiencies is limited due to the small number of occurrences. Levels above 200 to 300 ppm usually indicate a low pH or acid soil. Soil pH's of 5.5 or less are very common at this range. This is due to increased manganese availability in acid soils. High manganese is probably not a problem until 1,200 ppm or higher is reached. The toxic level is not well defined due to a lack of experience in California; it is based on European literature where toxic levels range up to 5,000 ppm. Vines with iron chlorosis problems will sometimes show deficient levels of manganese. These problems have been corrected with iron fertilization. The relationship to manganese nutrition has not been determined.

### **Boron**

Both deficiency and toxicity of boron are commonly found in California vineyards. Deficiencies occur in coastal highlands and granitic alluvial soils along the east side of the Central Valley. Toxicities are mostly associated with soils derived from the sedimentary coastal mountain ranges, especially where well waters exceed 1 ppm. Geothermic activity in or near wells accounts for other boron sources.

Petiole levels normally do not vary markedly along the shoot or during the growing season. However, in soils with high B, the petiole levels increase gradually throughout the season. Boron accumulates more in the blades. Thus, in high-B areas, the levels increase markedly during the season and are higher in the older leaves. Samples of affected blades will readily confirm toxicity.

### **Iron**

Critical levels for iron have not been established, because there is no correlation between iron and tissue levels. Deficiencies are related more to iron mobility with the plant rather



than the total iron levels. Petiole levels range widely from 50 to 300 ppm, with levels in most samples ranging from 70 to 200 ppm. Iron contamination of the sample from dust, equipment or other sources is a common analytic problem.

Iron deficiency problems in high lime soils should be addressed by utilizing lime tolerant rootstocks. The most tolerant ones used in Europe are 41-B and Fercal; neither have been extensively used or experimented with in California. Soil based treatments for iron deficiencies tend to be temporary, partially effective and expensive.

### **Chlorine**

Varietals and rootstocks differ widely in tolerance. Chlorine continues to accumulate during the growing season and does so predominately in the petiole, although the symptoms of excess appear in the blades. Leaf injury from chlorine sometimes occurs at petiole levels down to 0.8% in sensitive varieties such as Barbera when sodium is high. Blade analysis may help to confirm toxicity. In vineyards prone to high chlorine levels, it is advisable to avoid using chlorine-containing fertilizers in your fertigation program. If you are injecting chlorine as a bactericide into your irrigation system, you may want to alternate with other effective materials to lessen the total load of chlorine being put into your system.

### **Sodium**

Problems from excess sodium have not been well defined, because sodium and chlorine are almost always found together. Sodium may aggravate a chlorine problem. Petiole levels of over 0.5% sodium at bloom may indicate potential problems, particularly if potassium is relatively low. Visual symptoms of leaf margin discoloration (black staining) and necrosis have been associated with blade levels above 0.5% sodium. Symptoms of sodium toxicity are more likely to occur as the season progresses.



### **III. EQUIPMENT NEEDED FOR FERTIGATION**

**By Larry Schwankl, Terry Prichard and Glenn McGourty**

#### **A. Back flow Prevention:**

It is very important that injection equipment be properly installed to prevent accidental environmental contamination. A very big concern is that water that has been injected with chemicals might accidentally flow backwards into the irrigation source, with potentially disastrous consequences. Back flow devices prevent this from happening. Both state public health law (Title 17) and agricultural law (Title 3) require that irrigation systems which inject fertilizers, herbicides or pesticides have one of three backflow prevention devices: air-gap separation, reduced pressure principle backflow prevention device, or double check valve assembly. There may be additional laws that affect you, particularly if you are using a municipal water source, or if dwellings are also connected to your irrigation system. The more hazardous the material that you are injecting, the more backflow protection you should design into your system.

The reduced pressure double check valve (RPBB) assembly represents the highest level of back flow prevention devices. It is highly recommended that you use this valve if the consequences of accidental backflow are likely to be serious, such as contaminating a municipal water source, streams or rivers (especially inhabited by endangered species!)

Unfortunately, the reduced pressure double check valve assemble is quite expensive, requires periodic inspection and maintenance by a certified technician, and greatly reduces pressure delivered to the irrigation system. Because of its level of protection, commercial buildings are required in nearly all municipalities to have RBPB installed. Another draw back is that should the device sense back flow, it will divert all water to the drain part of the valve. Should this occur undetected by the system operator, it can result in serious local flooding or erosion. For big systems, it is advisable to install system pressure loss sensor switches or other fail-safe devices that will prevent unintended flow through the drain.

#### **B. Injection Equipment**

Injection equipment varies from very simple systems that are quite inexpensive and operate by the irrigation system's flow or pressure, to very sophisticated pumps that are extremely precise and are pressurized by their own electrical or gasoline powered motors. In general, the more precise the injection pumping system, the more expensive it tends to be. The choice of a system depends on the injector capabilities, reliability and cost.

##### **Batch Tank Systems**

Some of the earliest injector systems use batch tanks (see figure 1). These relatively inexpensive and simple systems consist of a tank that is plumbed into the irrigation system so that a portion of the irrigation system flows through it. The tank must be able to withstand the operating pressure of the irrigation system. Since there is often pressure loss as water flows through the batch tank system, the tank must be plumbed across a



pressure differential so that the batch tank inlet is at a higher pressure than the tank outlet. Examples of microirrigation system components that can cause a pressure differential are a partially closed valve or a pressure reducing (pressure regulating) valve. The rate that the material is injected is influenced by the flow rate through the tank and the concentration of injection material in the tank at any given time.

The batch tank is filled with the concentrated chemical (usually fertilizer) to be applied. During irrigation, water is allowed to flow into the batch tank, where it displaces some of the tank's contents, forcing them into the irrigation system. Initially, the liquid leaving the batch tank is of high chemical concentration, but with time the concentration in the batch tank becomes more diluted as it mixes with water. The chemical injection starts out at a higher concentration during the injection period. Batch tanks are appropriate if the objective is to inject a total amount of chemical during a long injection period to a specific area. Batch tanks are not appropriate if a constant injection concentration is required, as the concentration of the material being injected changes with time. They are also limited in the volume of material that they can apply, so they may not be a good choice for larger systems. Finally, since they are under pressure, they are potentially hazardous to operators if accidentally opened during use.

### **Venturi Injection Systems**

Injection devices using the venturi principle (figure 2) have been used for many years in a wide variety of industrial and agricultural applications. A venturi is a specially shaped constriction in a device's water flow path. As the flow passageway at the venturi section becomes smaller, the velocity of the flowing fluid increases such that a vacuum is formed at the venturi's throat section. An opening located in the venturi's throat allows air or a fluid to be "sucked" in and mixed with the water stream. To create this effect, the inlet pressure to the venturi must be at least 15 to 20 percent greater than the outlet pressure. This is achieved by plumbing the venturi device across a system pressure differential (e.g., a partially closed valve) (figure 3) or using a small pump that draws water from the microirrigation system and forces it through the venturi injector (figure 4). The injection rate of a venturi-type injector depends on the size of the venturi section (1/2 inch to 2-inch sizes are available) and on the pressure difference between the inlet and the outlet of the venturi.

The venturi injector delivers a more constant chemical injection rate than does a batch tank. However, the injection rate of a venturi injector can change (or even stop) if the pressure changes upstream or downstream in the microirrigation system. This can occur if irrigation sets (applications) with different flow rates are operated from the same water supply pump. A venturi injector installation in which the venturi is plumbed across a pressure differential (see fig. 3) is particularly sensitive to such changes, and it is often inconvenient to readjust the injector. The injector is usually installed in parallel to the microirrigation system pipeline, with valves that can be closed to isolate the injector from the irrigation system when injection is not occurring (see figs. 3 and 4). A venturi injector installation using a small pump in conjunction with the venturi eliminates the need to install the venturi across a pressure drop, and it also minimizes the venturi's sensitivity to



irrigation system pressure fluctuations. However, this type of installation requires an electrical or gasoline power source.

### **Positive Displacement Pumps**

Positive displacement pumps have a relatively small capacity and deliver a very constant rate of injection. They can be extremely accurate, and should be used if it is important to maintain a constant chemical concentration during irrigation. The pumps can use a cylinder-piston configuration (fig. 5) or a flexible diaphragm (fig. 6) to inject a liquid at a pressure higher than that of the irrigation system. Diaphragm pumps have an advantage over piston pumps in that they can be easily adjusted while the pump is operating. Their limitations are that they are sensitive to changes in mainline discharge pressure, and that the seals and other parts need routine maintenance and replacement. Piston pumps have an advantage over diaphragm pumps in that they aren't as sensitive to fluctuations in mainline pressure, and discharge flow rates won't change. Some are quite sturdy, and require lower levels of maintenance than diaphragm pumps. Their disadvantage compared to diaphragm pumps is that the flow rates can't be adjusted while the pump is running. Piston pumps that are adjustable require that you change the piston stroke, which can be done easily, but you must shut off the pump to do this. Many piston pumps have fixed rates, and to change the rate of injection into the irrigation system, you must change the concentration of stock solution being injected.

Electrically driven, gasoline engine driven, and water driven (fig 7) pump injectors are available. Positive displacement pumps provide the most accurate and constant injection rates, but they are also the most expensive injection devices. They do not need to be installed across a pressure drop since they are externally powered.

Positive displacement pump injectors are available as constant-rate pumps and as proportional pumps. Constant-rate pumps inject at a set rate (often adjustable) no matter what the flow rate is in the irrigation system. Proportional pumps (frequently water driven) inject at a rate dependent on the flow rate passing through the injector or through the irrigation system. For the electrical or gasoline-driven pumps, the injector is linked to the irrigation system via a flowmeter. For example, a proportional positive displacement injector set at 1:250 would inject 1 gallon of material for every 250 gallons of water passing through it. The proportional rate setting can be adjusted, as can the stock tank mixture concentration, to control the inject material's concentration in the irrigation system.

### **Injector Capacity and Price**

Many of the electrically powered piston or diaphragm injection pumps have adjustable injection rates and can inject concentrated materials in the 0-15 gallons per hour (gph) range. These cost about \$750 or more. Higher-rate injection pumps are available but they are more expensive. Table 1 lists the various injection devices and their relative costs. These positive displacement pumps are particularly well suited to injecting chemicals that must be injected at very constant, low concentration rates (e.g., chlorine or other microirrigation system maintenance chemicals.)



**Table 1. Relative injection capacities and costs of various injection devices.**

Type	Capacity	Cost
Batch Tank	Tank size	low
Venturi	18-140 gph	low
Venturi with Pump	18-140 gph	medium
Centrifugal Pump	high	medium
Piston Injector	low to medium	high
Diaphragm	low to medium	high

For fertilizer injections, many of the positive displacement pumps may have too low of an injection capacity. Small centrifugal pumps, often made of stainless steel, may be used where higher injection rates are desired, but it can be difficult to control the injection rate of these pumps. Make sure that the centrifugal pump selected can deliver the desired discharge rate against the operating pressure of the microirrigation system. Also make sure that the material being injected will not damage the pump.

### **Solutionizer Machines**

Solutionizer machines are a relatively recent development, and are very useful for injecting materials that usually are less soluble. These machines consist of a tank with an agitator and an injection pump. They are usually electrically powered. Solutionizers are useful for injection gypsum, potassium sulfate, and other materials that probably wouldn't work through conventional fertigation equipment, especially when trying to fertigate through microirrigation systems. The injection rate of the solutionizer machine should be adjusted to ensure that the injected material goes into solution prior to reaching any of the emitters. While the use of solutionizer machines has been an advance in chemigation, some caution must be used. Three issues are of concern: chemical precipitation, injected material solubility, and impurities in the injected material.

As with liquid materials, solid materials containing calcium should be injected with caution if the irrigation water contains substantial bicarbonates (greater than 2 mequ/l, or 120 ppm) and the water pH is greater than 7.5. The jar test should be performed before injecting any new product. Remember that gypsum, which is calcium sulfate, is a ready source of calcium.

Some of the materials injected by solutionizer machines, including gypsum, are not readily soluble in the irrigation water. The concentrations at which these materials are injected should be monitored to ensure that the material is going into solution. In addition, adequate time should be allowed for the materials to go into solution once they are injected into the irrigation system.



Impurities in the injected material are also a major consideration when using a solutionizer machine. Even the “pure,” finely ground gypsum materials prepared for use with solutionizer machines contain some impurities. If the material is 95 percent gypsum, 5 percent of it is still “foreign” material. Thus, for every 100 pounds injected, there will be 5 pounds of the foreign material, some of which may not go into solution.

Injecting granular fertilizers using solutionizer machines should be done with even greater caution. Many of these products may have been meant to be land-applied, and no particular care was taken in the production to minimize the impurities. Some have oil or wax coatings to prevent water absorption, and introducing insoluble materials such as these into microirrigation systems may lead to emitter clogging.

One option for dealing with suspended impurities is to inject the slurry from the solutionizer machine upstream of the microirrigation system’s filter. A filter cannot be located on the line from the solutionizer machine since the output from the machine is a slurry, and the injected material does not go into solution until it is injected into the main irrigation line. Use caution if the microirrigation system has sand media filters, an automatic backflush screen, or disk filter system. Any material injected while the filters are backflushing goes out with the flush water—a potential environmental concern when injecting fertilizers or certain irrigation system maintenance products.

### **Spray Rigs**

Some growers use their spray rigs for injecting fertilizer into their microirrigation systems. It requires minor plumbing changes on the sprayer and the irrigation system. The spray rigs act very much like a solutionizer, particularly if they have a mechanical agitation system to mix sprays and keep solids in suspension. Often, the pumps on spray rigs are of very high quality and are capable of generating considerable pressure. The system can be easily calibrated, and can be very useful if you are only occasionally injecting fertilizers into the irrigation system. It is advisable only to use readily soluble fertilizers in the spray, as other less soluble materials might be abrasive to delicate seals and other sprayer parts.

To use the sprayer, most growers plumb a shut off valve and a hose connection on the spray rig on the pressure side of the pump. As always, the irrigation system needs to have adequate back flow protection for the water source. A hose connection with a check valve (to insure that the solution can only flow into the system, and that the irrigation system won’t accidentally fill or pressurize the sprayer) and a shut off valve is also plumbed into the irrigation system. The sprayer can be calibrated by starting up the irrigation system, and running the sprayer pump until you have drained a known volume of water from the tank. Typically, the system is run at fairly low engine speeds (700—1000 rpm). By knowing the rate of injection, and the maximum amount of fertilizer that can be dissolved in water growers can fairly quickly determine an appropriate rate to fertilize their vineyard.

Drawbacks to this approach include the expense of operating a very large motor to do a fairly low energy requiring task (pumping), wear and tear on the sprayer, and tying up a



large piece of equipment that might be needed to do other things. This approach is probably best suited for small vineyard operations that only occasionally inject fertilizers or other chemicals into their irrigation system.

## **C. Equipment Layout and Design**

### **1. Manifolding and Valving**

The way in which an injector is plumbed into the irrigation system depends on how the device operates. Every system must have a back flow prevention device on the irrigation system mainline before the injection system. All fertigation systems must have check valves on the water supply to the injection device to insure that water can't accidentally flow backwards in a pressure loss and backflow event. All require shut off valves to isolate the injection system when it isn't being used.

If possible, injection equipment should be set up on a stable impermeable surface such as concrete to help contain minor spills. It is preferable that injection equipment not be located near well heads to avoid accidental contamination of the water source should a spill occur. If this isn't possible, be sure that the well head is adequately sealed from accidental fertigation system leakage, and that the well head is higher than the surface from which the injection equipment is located.

Connections between the injection equipment and the irrigation system should be leak proof and as permanent as is practical. If hoses are being used, maintain very clean and tight hose connections. Try to avoid having to connect and disconnect hoses. If you are using multiple materials to inject into the irrigation system, consider having either separate pumps, or a manifold that allows you to switch from tank to tank without having to disconnect and reconnect hoses on a regular basis. Hoses invariably spill and will be dumping concentrated materials which can be a source of environmental contamination. Also, this can be a source of contaminants into the injection system, particularly if the area is not clean and/or a hard surface.

If the fertigation system is going to be permanently mounted, take the time to plumb a neat and logical system. Secure the lines with pipe clamps so that they can't be easily moved or broken. If there will be multiple people operating the system, clearly mark valves, and post instructions on how to operate the system.

Devices that require differential pressure to operate (such as venturi-type injectors and batch tanks) must be plumbed across a system pressure differential, which is anything that causes a 15 to 20 percent loss in pressure between the inlet and outlet. Pressure reducing valves (which are often installed on microirrigation systems) and filters are sometimes used, and even a partially closed valve can be adequate for small systems.

For positive displacement pumps, inlets and outlets are plumbed onto the mainline with shut off valves and check valves to insure that water only flows one direction through the system.



### **Point of Injection**

The point in the microirrigation system at which materials are injected will depend on the material type. Readily soluble materials such as liquid fertilizers and chlorine should be injected downstream of the system's main filters. This will prevent the injected material from being part of the filter backflush water if filter cleaning occurs during injection. It is advisable to install a small screen or disk filter between the chemical solution tanks to the injectors to catch any impurities that may be in the material or tank.

Acid or other corrosive products used for microirrigation system maintenance should not be injected where low water pH may damage metal components (e.g., some sand media filter tanks). Most plastic components will not be affected by low water pH.

Materials injected by solutionizer machines should be injected upstream of the microirrigation system's main filters to remove any impurities in the injected material. Ideally, the injection should not occur while the filters are being cleaned. Control devices are available that can stop injection during back flushing operations.

To insure that the injected material and the irrigation water are mixed, materials should be injected into the middle of the water stream rather than at the pipe wall. Commercial devices are available that thread into the pipeline through a fitting and extend into the pipe, allowing injection directly into the fast moving irrigation stream. It is also possible to make such a device using PVC fittings and pipe.

## **2. Monitoring of Pressure and Fertilizer Materials**

Having a flow meter on your microirrigation system is an excellent idea, as you can determine flow rates to help calibrate your injection system. This is important especially if you have to maintain a very accurate amount of a particular chemical, such as chlorine for maintenance to prevent biological clogging in the system. Flowmeters are also useful to monitor the system to be sure that changes in the system's flow aren't occurring such as decreases from clogging, or increases from major leaks. For sophisticated systems, the flowmeters and injector pumps can be synchronized to insure uniform injection, regardless of flow. In most cases, the flow meter is installed before the fertilizer injection equipment.

Pressure gauges are useful to monitor the microirrigation system. Gauges are usually installed before and after filters. If you are using an injection device that requires a system pressure differential, pressure gauges should be installed before and after the fitting creating the change in pressure.

Clear tubing that allows you to see the movement of fertilizer into the injection system is used by some growers as a quick way of monitoring the fertigation process. This is practical for smaller systems in which the line between the fertilizer injector and pump is operating at low pressures, and the fertilizer solution is colored or opaque enough to see in the clear tubing.



Chemical monitoring of the solutions injected into the system is covered in Section V on Fertigation System Operations.

### **3. Tanks and Concentrated Fertilizer Containers**

Tanks that hold stock solutions should be made of materials that resist corrosion. Poly propylene and fibre glass are preferred materials by most growers due to their stability, and relatively inexpensive cost. Tanks constructed from 316 stainless steel can be used, but are quite expensive. On tank outlets to the injection system, all should be fitted with an off and on valve, and an easily cleaned 40 to 80 mesh filter. All water supplies to the tanks need to have back flow prevention devices, as simple as air gaps, back flow devices at the hose bibs or more complicated vacuum breaker and back flow prevention devices if the water supply to the tanks are permanently plumbed into the water system. If the system is going to be permanent, tanks should be placed on a stable and weather proof surface, such as gravel, compacted road base, asphalt, or concrete .

Containment structures are also advisable, especially if the system is permanently fitted. These structures can be as simple as placing the fertilizer tanks in open topped poly or fibre glass tanks large enough to contain the contents of the stock tank if accidentally emptied. More expensive structures may use formed concrete, or concrete slabs with cinderblock walls. The more hazardous the material that you are storing, the more elaborate the containment system needs to be.

It is advisable to also label the tanks if you keep stock solutions in the same tank on a regular basis. This is very important if the solution is corrosive or toxic.



## **VI. FERTILIZER MATERIALS AND AMENDMENTS FOR FERTIGATION**

### **A. Solutions and suspensions**

Fertigation is easiest when the fertilizer material that you are applying dissolves completely in water, forming a solution. Not all fertilizers are suitable for fertigation. Fertilizers manufactured primarily for conventional dry applications often have coatings or conditioners that keep them from absorbing moisture from the air. These coating materials are not soluble, and include substances like clays, diatomaceous earth and hydrated silica. These materials have the potential to clog the emitters in your system. It is best to test a small amount of material by mixing it with water in the proportion that you will use for your stock solution, and see if the coating will rapidly sink to the bottom. The clear portion of the stock solution can then be carefully removed without disturbing the conditioner, and will be suitable for injection. The conditioner has to be removed from the tank and disposed of, which becomes problematic if you are fertigating on a regular basis. If you are going to use any coated fertilizers, it is highly recommended that you inject into the system *before* the filters.

Whenever using dry fertilizers for your stock solutions to be injected, choose materials that are formulated as “Solution Grade”, for these materials are much less likely to cause plugging. Typically, they do not have insoluble conditioners coating the material. If “Solution Grade” materials are not available, it is best to purchase a concentrated liquid form of the fertilizer. In most cases, these are specialty materials that are not readily available at the local farm supply.

Liquid fertilizers are normally clear, and are formulated for injection into closed irrigation systems. Manufacturers often include a colored dye for easy material identification. At this time, there is no standardized color code for the fertilizer industry.

Suspension fertilizers are not suited for injection into closed irrigation systems. These materials are made by mixing large amounts of fertilizer into water with emulsifying agents that suspend the nutrients in the liquid at concentrations that exceed the solubility of the chemicals. These materials are formulated to be applied by ground application rigs that use large spray booms, flood-type nozzles and high pressure pumps.

### **B. Determining How Much Material to Use**

#### **Pounds Per Acre versus Parts Per Million**

Strategies for fertigation differ, based on the age of the vineyard, and how often it is necessary to fertilize the vines. Two different approaches can be made. If fertigation is infrequent, then you can calculate on pounds of fertilizer to apply on a per acre basis. If you are feeding often, such as during vineyard establishment, and if you want to encourage fairly rapid vegetative growth, you may want to consider your application



rates on a part per million (ppm) basis. Determining ppm rates is also important if you need to condition water, or apply chlorine in the irrigation system.

### **System Information that You Will Need to Know:**

- Flow rate of the irrigation system during injection
- Injection pump flow rate in gallons per hour, or proportion (i.e., 50:1, 100:1)
- Analysis of the material that you want to inject
- Desired concentration of the material (ppm method) or rate of material per acre
- Amount of time that you will be injecting materials (length of fertigation cycle)

### **1. Pound Per Acre Method**

When fertigation is done less frequently, the Pound Per Acre method to determine fertilizer mixing rates can be used, and it will be quite accurate from the perspective of total material applied per acre. For an example, let us suppose that we want to fertigate a 10 acre block of wine grapes with calcium nitrate (17-0-0) at the rate of 5 lbs of N per acre. We are using an injection pump that injects at the rate of 15 gallons per hour. Our stock tank holds 100 gallons. How much material should we use dissolved in how much water? Will our system be able to inject all of the material in one set? How long will the irrigation system have to run to inject the material?

**Step 1:** *Determine the amount of material to be applied during the fertigation:*

We will apply 5 lbs of N.

**Step 2:** *Determine the material to be used:*

In this example, it is calcium nitrate, 15.5-0-0.

**Step 3:** *Determine the pounds of the selected fertilizer to use:*

The following equation can be used:

$$\frac{\text{Pounds of Nutrient}}{\text{Acre}} \times \frac{100\% \text{ Fertilizer}}{\% \text{ of fertilizer being used}} = \frac{\text{Pounds of Fertilizer}}{\text{Acre}}$$

In our case:

$$\frac{5 \text{ lbs N}}{\text{acre}} \times \frac{100\% \text{ calcium nitrate}}{15.5\%} = 32.25 \text{ lbs calcium nitrate per acre}$$

**Step 4:** *Determine the amount of water needed to make a stock solution to fertigate:*

From Table 2, we see that we can dissolve up to 10.11 lbs in one gallon of water.

The following equation can then be used:



Pounds of Fertilizer to be applied per acre X number of acres  
Amount of fertilizer that can be dissolved in 1 gallon

In our case:

$$\frac{32.25 \text{ lbs per acre} \times 10 \text{ acres}}{10.11 \text{ lbs}} = 31.9 \text{ gallons of stock solution}$$

Since our stock tank holds 100 gallons, 31.9 gallons of stock solution will easily fit

**Step 5:** *Determine the total time for fertilizer injection:*

$$\frac{\text{Total amount of stock solution to be injected}}{\text{Pump injection rate (gallons per hour)}} = \text{Fertigation run time}$$

In our case:

$$\frac{31.9 \text{ gallons}}{15 \text{ gallons per hour}} = 2.1 \text{ hours}$$

## 2. PPM Approach

Calculating your fertilizer applications on a parts per million basis makes some sense if you are planning to fertigate on a regular basis. The nursery industry has developed extensive experience with this approach. In container nurseries, nitrogen and other fertilizers are injected into irrigation water at rates varying from 50 to 600 ppm on a weekly basis, depending on crop needs for nitrogen. Unfortunately for grape growers, there are no standards that have been set for vineyards based on a ppm basis. Greenhouse rates reflect plants growing in artificial mediums with limited root systems, and do not take into account residual nitrogen in the rooting zone, which would be present in vineyards.

To consider developing a program based on a PPM basis, you need to have calibrated equipment that can give you a predictable injection rate. Positive displacement fertilizer injectors are especially well suited for this task. Following are rates if you wish to develop a fertilization program based on a ppm approach. They are based on pure material to be injected.

Table : PPM and Rates in Different Volumes of Water\*

PPM	1 gallon	100 gallons	1000 gallons	Acre Foot (325,851 gal.)
1 ppm	0.00013 oz	0.013 oz.	0.13 oz.	2.7 lbs
50 ppm	0.0066 oz	0.66 oz.	6.6 oz.	135 lbs
100 ppm	0.0132 oz	1.32 oz.	13.2 oz.	270 lbs
200 ppm	0.264 oz	2.65 oz.	26.5 oz.	540 lbs

\*2.7 lbs in an acre foot of water= 1ppm



To calculate the amount of fertilizer needed at a specific ppm rate, use this equation:

$(0.00013 \text{ oz}) \times \text{ppm desired} / \% \text{ material in fertilizer} \times \text{gallons per hour of water applied with fertigation} \times \text{number of hours that water is injected}$

Example 1: Suppose that you wanted to inject 100 ppm on a weekly basis (one application per week) while irrigating your vineyard using calcium nitrate 15.5-0-0 as the N source. Your vineyard is planted 8 feet by 6 feet, for 907 vines per acre. You irrigate each vine with 2 half gallon emitters, for a total of 907 gallons of water per hour. You will inject fertilizer for 6 hours, allowing an additional 2 hours to flush the system, for a total of 8 hours per set. How much fertilizer would you need (and apply) for each acre of vines per week?

In this example:

$N = (0.00013 \text{ oz.}) \times 100 \text{ ppm} / 0.155 \times 907 \text{ gallons} \times 6 \text{ hours} = 456 \text{ ounces} = 28.5 \text{ lbs calcium nitrate/ acre (4.42 lbs N)}$

### **The Rule of 75**

When determining fertilizer rates for fertigation, it is common to express the nutrient content injected into the water in terms of parts per million (ppm). It is quite easy to calculate ppm with a standard equation (sometimes referred to as “the rule of 75”):

1 ounce of fertilizer (pure)/ in 100 gallons of water = 75 ppm

Since there are no pure fertilizers, you must refer to the analysis numbers on the fertilizer bag to determine the actual amount of a particular fertilizer to be used. As an example, say that you mixed 1 ounce of 10-15-15 fertilizer into one gallon of water. What is the concentration of the different nutrients in the water?

To solve the problem, we multiply one ounce X percent fertilizer concentration (from the label analysis) X 75 ppm

In our case, for N: 1 ounce X .10 X 75 ppm = 7.5 ppm N

For P and K: 1 ounce X .15 X 75 ppm = 11.25 ppm

To determine how much fertilizer to add to water to get a desired solution, the following formula can be used:

$\frac{\text{desired ppm}}{\% \text{ nutrient analysis}} = \text{oz of nutrient source per 100 gallons}$



As an example, suppose that you wanted to inject a solution that will result in 200 ppm nitrogen and we have 20-10-20 analysis material available. Using our formula:

$$\frac{200 \text{ (which is our desired ppm concentration)}}{0.20 \text{ (fertilizer analysis for N)}} \div 75 \text{ (a constant)} = 13.33 \text{ ounces /100 gal}$$

### How Much Material in a Stock Solution, and How Much Stock Solution?

Next, we need to know how much material that we can put into a concentrated stock solution. Table 2 indicates the maximum amount of specific fertilizers that can be dissolved in a gallon of water.

**Table 2. Solubility of various fertilizer compounds used for fertigation**

Material	Grade	Form	Solubility gm/100ml	Solubility Pounds/gal
Ammonium nitrate	34-0-0	NH <sub>4</sub> NO <sub>3</sub>	18.3	9.87
Ammonium sulfate	21-0-0	(NH <sub>4</sub> )SO <sub>4</sub>	70.6	5.89
Calcium nitrate	15.5-0-0	Ca(NO <sub>3</sub> )	121.2	10.11
Urea	46-0-0	CO(NH <sub>2</sub> ) <sub>2</sub>	100	8.34
Potassium Chloride	0-0-60	KCl	34.7	2.89
Potassium nitrate	13-0-44	KNO <sub>3</sub>	13.3	1.10
Potassium sulfate	0-0-50	K <sub>2</sub> SO <sub>4</sub>	12	1.0
Potassium thiosulfate	0-0-25-17S	K <sub>2</sub> S <sub>2</sub> O <sub>3</sub>	150	12.5
Borax	11% B	Na <sub>2</sub> B <sub>4</sub> O <sub>7</sub> . 10 H <sub>2</sub> O	2.1	0.17
Boric Acid	17.5% B	H <sub>3</sub> BO <sub>3</sub>	6.35	0.53
Solubor	20 % B	Na <sub>2</sub> B <sub>8</sub> O <sub>13</sub> . 4H <sub>2</sub> O	22.0	1.84
Copper sulfate (acidified)	25% Cu	CuSO <sub>4</sub> .2H <sub>2</sub> O	31.6	0.17

Finally, we need to know what proportion that your fertilizer injector works at. If you are using a 100:1 proportioner, you will be injecting one gallon of concentrated fertilizer for 100 gallons of irrigation water. To determine what size stock tank that you need for your injection, you use the following relationship:

$$\frac{100 \text{ gallons flow}}{1 \text{ gallon of stock fertilizer}} = \frac{\text{amount of water during fertigation cycle}}{\text{x gallons of stock fertilizer}}$$



If we are going to apply our fertilizer to the vineyard in a 6 hour set, using a 100:1 proportioner, the following relationship will exist:

Vineyard irrigation flow rate in gph X hours to do injection / 100/1 = amount of stock solution needed per acre being fertigated.

Let us consider a vineyard planted 8 feet X 6 feet, which requires 907 gallons per hour of irrigation water and we will inject fertilizers for 6 hours during an 8 hour irrigation:

$907 \text{ gph} \times 6 \text{ hours} / 100 / 1 = 54 \text{ gallons of stock solution per acre.}$

Suppose that we wish to use calcium nitrate to fertigate at 100 ppm for a 6 hour injection. How much material do we need to mix into the 54 gallons of stock solution per acre? From Table 2, we look up how much calcium nitrate that it takes to make 100 ppm solution in 100 gallons. The amount is 8.3 ounces per 100 gallons. We set up a proportion:

$$\frac{907 \text{ gph} \times 6 \text{ hours}}{x \text{ calcium nitrate}} = \frac{100 \text{ gallons}}{8.3 \text{ ounces calcium nitrate}}$$

Solving the equation by cross multiplying and dividing:

$(100 \text{ gallons})x = 451 \text{ ounces} = 28 \text{ lbs of calcium nitrate in 54 gallons of stock solution per acre.}$

The final step is to determine if we can dissolve 28 lbs of calcium nitrate into 54 gallons of water for the stock solution. Referring to Table 2, we see that we can put 10.11 lbs of calcium nitrate into a gallon of water. 28 lbs will easily dissolve in 54 gallons.

**Table 3. Ounces of Fertilizer To Supply 25, 50, 100 and 200 Parts Per Million (ppm) in 100 gallons of water**

Material	Analysis	25 ppm	50 ppm	100 ppm	200 ppm
Ammonium sulfate	21-0-0	1.6	3.2	6.35	12.7
Ammonium nitrate	33.5-0-0	1.0	2.0	4.0	8
Urea	45-0-0	0.7	1.5	3.0	6
Calcium nitrate	15-0-0	2.1	4.2	8.3	16.7
Potassium choride	0-0-62	0.7	1.4	2.8	5.6
Potassium Sulfate	0-0-51	0.6	1.3	2.6	5.2
Potassium thiosulfate	0-0-25	1.3	2.7	5.3	10.66



## **B. Specific Fertilizers Used for Fertigation**

### **1. Nitrogen sources**

Supplying nitrogen to the vineyard through a drip system is very efficient, and there are many sources that you can use.

#### **Urea**

Urea is available as both a solid material (46-0-0) and as urea solution (23-0-0). If growers routinely fertigate, the solution form is very convenient to use. Solid urea will dissolve readily into water. Urea is noncorrosive, and relatively safe to use. Urea fertilizers can contain a polymer called biuret, which can occur up to 2.5%. The biuret materials can be phytotoxic, and should not be used if your fertigation water is going to contact green tissue. Low biuret is available and recommended if fertilizer solution is going to contact foliage.

#### **Calcium Nitrate**

Calcium nitrate is a solid material (15.5-0-0-19 calcium) that dissolves readily in water. Usually the prills are coated to keep the fertilizer from absorbing moisture from the air. It is often used by fruit growers and others who want to apply calcium as a nutrient along with nitrogen.

#### **Calcium Ammonium Nitrate or CAN-17**

Calcium ammonium nitrate is a liquid (17-0-0-8.8) often used by both fruit and vegetable growers who wish to apply calcium as a nutrient. CAN-17 is often mixed with different potassium fertilizers. It shouldn't be mixed with any materials containing phosphorus, sulfates or thiosulfates.

#### **Ammonium Sulfate**

Ammonium sulfate (21-0-0-24S) is an inexpensive and widely used nitrogen fertilizer. It also contains sulfur, which can be deficient in some parts of California. It dissolves readily in water, and is convenient to use for fertigation. It tends to be acid forming, which could be a disadvantage if your vineyard soils are acidic.

#### **Urea Sulfuric Acid**

Urea sulfuric acid is a specialty chemical available in several different formulations. It is a liquid fertilizer known commercially as N-pHURIC. Besides providing nitrogen, this compound helps to acidulate irrigation water, and is useful in reducing carbonates and bicarbonates should they be a potential problem. While corrosive, it is still safer to handle than sulfuric acid. Urea sulfuric acid also can be used help prevent calcium carbonate deposits from forming in drip systems. If mild plugging has occurred, urea sulfuric acid can help to clean up the system and in some cases, restore normal flow through the



emitters. Urea sulfuric acid is a soil acidifier, and can help to lower the pH in alkaline soils. This in turn may make some of the micronutrients more available.

## **2. Potassium Sources**

Potassium doesn't move readily through the soil profile like nitrogen, and it is difficult to supply grape vines showing potassium deficiency symptoms solely by fertigation. Since there are forms of potassium that are more mobile than others, it can still be a useful strategy to use fertigation as a way of increasing potassium in the soil solution around grape vine roots.

### **Potassium Chloride**

Potassium chloride (0-0-62) is widely used as a potassium source, as it is relatively inexpensive, and fairly water soluble, especially compared to potassium sulfate. If background levels of chloride are already high in either your irrigation water or soil, this may not be a suitable choice.

### **Potassium Nitrate**

Potassium nitrate (13-0-46) is used when you wish to apply both nitrogen and potassium in one operation. It is more expensive than potassium chloride and not as soluble. It mixes well in water, and works well in most microirrigation systems.

### **Potassium Sulfate**

Potassium sulfate (0-0-50-18S) is the least soluble form of potassium that can be fertigated. Growers typically use solutionizers to inject this material due to its low solubility. There are small particle size formulations available for fertigation. This material is also a useful source of soil sulfur, if that is required in your fertility or soil management program.

### **Potassium Thiosulfate**

Potassium thiosulfate (0-0-25-17S) is a liquid fertilizer that can be easily injected into irrigation water. It is used to fertigate plants growing in soils high in calcium and magnesium. The thiosulfate is converted over time to sulfuric acid, and this can react with calcium carbonate to release calcium for the plant. Grower experience indicates that this can be a good source of potassium for grape vines grown in soils with high magnesium content, as well.

## **3. Phosphorus Sources**

Since phosphorus is rarely deficient in grape vines, you probably will not have to apply phosphorus fertilizers through your drip system. There are a few instances where phosphorus might be deficient, such as on very low pH soils, or following soil fumigation. Most dry phosphorus fertilizers packaged for general use cannot be used for fertigation, as they are fairly insoluble. Soluble formulations made from phosphoric acid or ammonium phosphate are used for fertigation.



Remember that phosphorus containing fertilizers should never be mixed with any other materials containing calcium. Chemical precipitation is likely, which can permanently clog emitters. Hard water (high in calcium) can also cause precipitates to form. Because of the expense of water soluble formulations and the risk of emitter plugging, it is probably best to address phosphorus deficiencies with land applied fertilizer applications.

### **Phosphoric Acid**

Phosphoric acid (0-54-0 “white” or 0-52-0 “green”) are both used for fertigation. White phosphoric acid is a food grade material, and it is expensive and not readily available to purchase. It is the preferred material for injecting into microirrigation systems. Green phosphoric acid is more common, but has impurities in it. These are both liquid formulations that can be easily diluted in water.

### **Ammonium phosphates**

This group of fertilizers are made by ammoniation of phosphoric acid, often mixed with other materials. Common materials include monoammonium phosphate (11-52-0) also known as MAP, diammonium phosphate (18-46-0) and ammonium phosphate sulfate (16-20-0-15S). Liquid forms of ammonium phosphate include 8-24-0, 9-30-0, and 10-34-0. These materials can be injected only at relatively low rates, and can cause emitter plugging problems if the irrigation water is hard.

## **4. Micronutrients**

Micronutrients can be applied readily through the drip system. Sulfates of copper, iron, manganese, and zinc dissolve readily in water, and move well through the drip system. Since the ionic form of these nutrients are adsorbed readily by soil, their effectiveness may be quite limited. Chelated forms are more likely to be effective, and can be easily injected. Chelating agents containing EDTA, DTPA, and EDDHA are not compatible with acidic solutions, and should not be mixed with other acid forming materials.

Boron is anionic in nature, and can easily be fertigated. Borax and Solubor are two formulations of sodium borate that are fairly soluble and very effective materials.

## **5. Gypsum**

Gypsum is used primarily as a water conditioner when fairly pure irrigation water is causing soils to seal, and an increased calcium content is needed to correct this condition. The other situation in which gypsum is used occurs when growers are trying to improve soil tilth and potassium uptake in high magnesium soils, especially those derived from serpentine rock. If you are injecting gypsum to treat water, most consultants will recommend continuous treatment. Occasional injections are considered ineffective. No research data exists for the long term affects of gypsum treated water on high magnesium soils.



Solutionizers are used to inject gypsum into irrigation systems. These machines help to dissolve the gypsum before the material is injected into the irrigation water.

Gypsum occurs in two different forms, and has a range of purity. The dihydrate form of gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ , molecular weight 172.2) dissolves rapidly because of the attached water molecules. The anhydrate form ( $\text{CaSO}_4$ , molecular weight 136.1) will dissolve more slowly.

It is advisable to find a fairly pure source of gypsum that has a greater content of dihydrate rather than anhydrate form. The material should be ground fine enough to pass through a 200 mesh screen.

Injections of gypsum should be made before the filters, since impurities may not dissolve in water and go into solution.

The practical limit of anhydrite gypsum injections is reported to be 1000 ppm. This is equivalent to the following:

- 1265 ppm dihydrate gypsum
- 14.7 meq/l of calcium
- 2720 pounds of pure anhydrite per acre-foot
- 3440 pounds of dihydrate per acre-foot

### **C. Organic Fertilizers**

#### **Overview**

Organic wine growing is widely practiced in parts of the North Coast, and there are also organic wine growers in nearly every other part of the state. Organic wine growing requires considerable attention to soils management, and nutrients are usually supplied to the vines by a combination of nitrogen fixing cover crops and well made compost. In most cases, this is sufficient for adequate nutrition for the vines. Occasionally, it may be necessary to add additional fertilizer during the growing season. Fertilization is a limited option for organic growers, as there are not too many organic fertilizers that can be injected into the irrigation system without the risk of clogging emitters. Additionally, some of these materials are quite expensive for the nutrients that they supply.

Since many organic fertilizers are quite attractive to microorganisms, it is important that the application of the materials are followed by a long flushing cycle of clean water. Many growers also flush the ends of the lines following an organic fertilizer injection to be sure that nothing has settled in the system.

#### **1. Fish Emulsions:**

Fish emulsion is of limited value for use in drip systems, as it tends to clog emitters. If you are going to try to use it, inject the material before filters to insure that should



clogging occur, the filters are the only part of the system affected. No research based guidelines are available for suggested rates or injection procedures.

## **2. Hydrolized Animal Protein:**

Hydrolized animal proteins are byproducts of the meat and seafood industry made by processes that involve enzymatic digestion of meat and fish scraps, concentration into liquid protein in vacuum columns, and then spray drying of the materials using rotary nozzles in cyclone tanks at high wind speeds and moderately low drying temperatures. The resulting materials are quite high analysis (10 or 12 percent nitrogen), and the particle sizes are sufficiently low to pass through a 200 mesh screen. In trials by the authors, fish and chicken hydrolyzed protein could be successfully injected up to 75 ppm N, and stayed suspended for up to 400 feet from the injection source. The stock solution required constant agitation to prevent settling of the material. Hydrolized blood protein did not work as well, and while clogging was not a problem, it had a tendency to fall out of the water as it traveled through the drip system, resulting in uneven distribution of the fertilizer. Fertilizer injections were made with both a water driven piston pump, and an electrically driven diaphragm pump. These materials are probably the best option for growers that wish to fertigate their vineyards with organic fertilizers. It is advisable to inject these materials before the filter system to avoid potential clogging.

## **3. Potassium Sulfate:**

Mined sources of potassium sulfate are allowable as a potassium fertilizer in certified organic programs. Finely ground potassium sulfate can be injected into the irrigation system. Solutionizer machines are often used for this. Injections should be made before the filter system to avoid clogging. Dry applications of potassium sulfate beneath the emitters are probably a more efficient way to apply this fertilizer.

## **4. Kelp and Seaweed Products:**

There are different types of fertilizer products containing seaweed extracts that contain both micronutrients and growth regulators. While many of these will go through a drip system, in most cases, the benefits from using these relatively expensive products are probably greatest from foliar applications. No experimental data exist on the effects of using seaweed concentrates for fertigation.

## **5. Compost teas:**

Grower experience indicates that compost teas can be made and injected into the irrigation system. The compost must be thoroughly mixed, settled and strained so that all particulates are removed. Injection must be made before the filter system to avoid potential clogging of emitters. No experimental data exist on the effects of using compost tea for fertigation. Dry applications of compost beneath the drip emitters is probably a more logical way to use compost in a vineyard.



## **V. Fertigation Systems Operations**

**By Larry Schwankl, Terry Prichard and Glenn McGourty**

### **A. Water Management and Scheduling**

Irrigation management in the vineyard is changing as wine quality becomes an important objective for the grower. Increasingly, growers seek to limit the extent of vegetative growth of the vine to provide adequate but not excessive shoot growth. By limiting irrigation following bloom and fruit set, growers can influence the vine to produce fruit with smaller berry size and lighter, looser clusters. For red varieties, this often results in more concentrated flavors and color in the wine made from fruit managed this way. In white varieties, flavor concentration often increases with smaller berries and lighter clusters.

While limiting irrigation to control canopy growth, fruit size and yield, it is important not to stress vines during ripening. Fruit quality can suffer if vines are so stressed that they stop many physiological functions that are necessary during fruit ripening. Consequently, many growers apply water more regularly as the season progresses and avoid stressing the vines as harvest approaches. Some growers will even over irrigate to slow down ripening near harvest. Heavy irrigations can slow down sugar accumulation; at the same time, it might allow seed tannin maturity and fruit acid reduction for more balanced wine flavors. Another reason might be to delay ripening and harvesting for winery convenience, as when large amounts of fruit are ripening simultaneously, and all of the tanks are full of fermenting juice.

The concepts of deficit irrigation and partial root zone drying are based in the idea of limiting water to grape vines to influence vine and fruit growth at key times in the annual growth cycle of the vine. Many irrigation specialists believe that stored soil moisture should be at its highest level at the start of the growing season. Vine water status should be monitored throughout the season by use of pressure bombs, and irrigation should begin about when the leaf water potential reaches between  $-10$  and  $-12$  bars. This normally occurs after fruit set, and the calendar date varies greatly depending on location, variety, soil type, crop load, weather and all other factors that affect vine water use and growth. In the North Coast, it is not unusual for bud break to occur in early April, flowering to occur in mid-May, and the first irrigations to be applied during mid-late June.

Microirrigation allows considerable flexibility in how water can be applied. The object is to replace water as it is used by the vine, hopefully in a manner that allows vine physiology to continue at an uninterrupted rate. There are different strategies to accomplish this, but many center around ET measurements and depletion rates of soil moisture. This is frequently expressed as a fraction of inches of water depleted per day. Since most microirrigation system flow rates are described in gallons per hour, it is helpful to know what the operating time might be for your system to replace a fraction of an inch of water used from the soil profile.



### How Much Water is Being Applied?

The water use of the crop and the application rate of the emission device(s) determines how long drip and micro-sprinklers should be operated.

**Step 1** in determining the required operating time is to convert the crop water use information (usually expressed in inches per day) to gallons per day of plant water use. The following formula may be used (or see Table ?):

$$\begin{array}{l} \text{Water use} \\ \text{By the plant} = \end{array} \begin{array}{l} \text{Plant} \\ \text{Spacing} \\ \text{(ft.)}^2 \end{array} \times \begin{array}{l} \text{Crop water} \\ \text{use} \\ \text{(inches/day)} \end{array} \times 0.623 \text{ ( a constant)}$$

Example: A vineyard planted 8 ft. x 5 ft., vine water use for that day = .15 inches per day

$$\text{Water use by the plant: } 40 \text{ ft.}^2 \times 0.15 \text{ inches} \times 0.623 = \underline{3.75 \text{ gallons/day}}$$

**Step 2** is to determine the application rate of the irrigation system in gallons per hour (gal/hr). For both drip emitters and micro-sprinklers, this requires determining: (1) the number of emission devices per plant, and (2) the discharge rate per emission device (gal/hr/emitter):

$$\begin{array}{l} \text{Application} \\ \text{Rate (gal/hr)} \end{array} = \begin{array}{l} \text{Number of} \\ \text{Emission Devices} \end{array} \times \begin{array}{l} \text{Discharge Rate per} \\ \text{Emission Device (gal/hr/emitter)} \end{array}$$

$$\text{Example: } 2 \text{ emitters per vine, discharge rate per emitter} = .5 \text{ gal/hr} \times 2 \text{ emitters} = \underline{1 \text{ gal/hr / vine}}$$

**Step 3** is to determine the irrigation system operation time in hours per day. This requires the crop water use (determined in Step 1) and the application rate (determined in Step 2). The following formula may be used:

$$\text{Hours of operation per day} = \frac{\text{Vine Water Use (gal/day)}}{\text{Application Rate (gal/hr)}}$$

$$\text{In our example: } 3.75 \text{ gallons per day} / 1 \text{ gallon per hour} = \underline{3.75 \text{ hours of irrigation run time per day}}$$

**Step 4** is to determine how long to run the system for each irrigation cycle:

$$\text{Hours of operation per cycle} = \text{Sum of Hours of irrigation run time per day since the last irrigation}$$

Example: Our grower likes to irrigate once or twice a week depending on how much water is needed by the vines. In this week:

Day:	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Run Time:	3.75	3.75	1.8	2.5	3.75	1.8	1.8

Week Total: 19.15 hours of system run time



If he likes to run his irrigation system in 8 hour sets, he would irrigate most likely on Tuesday, and again on Saturday. (Monday + Tuesday run times = 7.5 hours; Wednesday + Thursday + Friday = **8.05 hours**)

### **Calendar Methods**

Many growers are much less precise about their irrigation scheduling. Many wait until they see the tendrils from shoot tips dropping, and the internodes on new growth becoming quite short, indicating that growth is slowing down due to moisture stress. At this point, they begin to water. Many use a preselected number of hours per week, such as two 8 hour sets, or whatever experience has shown them to be adequate to maintain healthy vines. This approach is not very precise, and inevitably, the vines are being either over or under irrigated. By using a pressure bomb to establish a threshold to begin irrigating, and checking between irrigation cycles, growers can implement a much more precise program to determine when to irrigate. Soil moisture monitoring can also considerably improve knowing what is happening in the root zone. When combined with pressure bomb monitoring of the vines, growers can become very effective at developing more accurate irrigation programs.

## **B. Fertigation Strategies and Procedures**

Growers take different approaches to fertigating, depending on the kind of system that they have, the ease with which materials can be applied, and the nutrient that they are trying to supply.

When grape vines are young, frequent fertigation with small amounts of nutrients is a way to promote rapid growth, especially when coupled with light, frequent irrigations. This strategy is especially useful in difficult sites where soils have low water holding capacities or are quite infertile. Since the vines' root systems are constantly growing and expanding, you are ensuring that there is always a steady supply of nutrients in place for the vines.

Vines that are fully developed probably do not need to have fertilizer applied as often. Grower experience and research indicates that grape vines are quite efficient in absorbing nitrogen in one fairly large application, compared to applying the same amount in several smaller applications. Either approach is effective. Since there is a practical limit to the amount of fertilizer that can be dissolved and injected into the irrigation water, several applications of nitrogen fertilizer probably makes sense. Growers typically apply materials post bloom, and again in the fall post harvest.

Vines with impaired root systems (such as damage from phylloxera or nematodes) also benefit from frequent, light feeding. This approach ultimately will not save a vineyard, and replacement of the vines with tolerant or resistant rootstocks will be necessary. It may be able to keep the vineyard in production for several additional years, which can be economically viable and necessary for the grower.



### **Guidelines for Mixing Stock Solutions**

When you are ready to begin fertigating, the first step in the process is mixing up the stock solutions. Following are some guidelines for safe and effective mixing procedures:

- i. Always begin by filling the stock solution container with at least 50% of the water to be used
- ii. Liquid concentrates should be mixed in before adding dry concentrates
- iii. Add dry ingredients slowly. Providing agitation or circulation in the tank is an excellent idea.
- iv. Always put acids into water, not water into acids.
- v. *Never* mix chlorine with any acids. To be safe, chlorine should always be applied by itself.
- vi. Don't mix concentrated fertilizer solutions directly with other concentrated fertilizer solutions. Always dilute in water one at a time into the stock solution tank.
- vii. Don't mix compounds containing sulfate with another compound containing calcium. The result will be insoluble gypsum.
- viii. Do not mix phosphorus fertilizers with materials containing calcium .
- ix. If you have very hard water (large amounts of calcium and magnesium), you may precipitate sulfates or phosphates, which can clog emitters. *Always test irrigation water before you begin a fertigation program, and consult with fertilizer specialists on what you plan to inject .* Be cautious, and avoid using compounds containing sulfur or phosphorus.
- x. If you are uncertain about compatibility between different fertilizers, always perform jar tests, and check for precipitation or other problems BEFORE mixing larger batches of materials.
- xi. If the material to be injected is formulated to apply as a dry fertilizer, it is advisable to dissolve it in advance and decant the clear stock solution from any solids that might fall to the bottom of the tank.
- xii. If you are changing materials in your stock solution tanks, be sure to thoroughly rinse and purge all equipment before mixing up new concentrates.
- xiii. If you fertigate infrequently, it is advisable to mix only the materials that you need for each injection cycle. Following injections, it is a good idea to thoroughly rinse all of your equipment, including the stock solution tanks. This helps to prevent corrosion in your pumps and plumbing, and lessens the opportunity for accidental spills from leftover concentrated materials.



### **Injection Timing and Duration**

When injecting materials through a microirrigation system, two objectives should be kept in mind. First, the irrigation amount applied should be correctly determined so that the applied water and injected material remain in the plant's root zone. Applying more irrigation water than the plant's root zone can hold (overirrigation) causes water to percolate deep below the root zone. Overirrigation can also cause the injected material to percolate out of the root zone if the injected material travels through the soil easily with the water (e.g. nitrates). Good irrigation scheduling techniques can minimize this hazard and optimize the efficiency of chemigation. *A good time to inject material is in the middle of an irrigation set* (assuming that the irrigation set is long enough to allow a choice of when to do the injection). This makes it more likely that the injected material will stay in the root zone if overirrigation occurs.

Second, the duration of injection should provide a uniform application of injected material throughout the microirrigation system. It is important to remember that the injected material does not immediately reach all of the emitters as soon as injection begins. A period of time is required for the water and the injected material to move through the system to the emitters. This travel time depends on the design and layout of the microirrigation system. In the following discussion of travel times, it should be assumed that injected materials travel through the microirrigation system at the same speed as the irrigation water.

Water travels through a microirrigation system's mainline and submain pipelines quite rapidly. These pipelines are typically sized so that the flow velocity is less than 5 feet per second (fps) to minimize frictional pressure losses. Flow velocities of 1 to 3 fps are quite common in mainline and submains. Some pipeline systems are long, so movement of water and injected materials through them may take a while: travel times of 20 to 30 minutes are common, and travel times as long as 65 minutes have been observed (see Table ?).

Irrigation water flows slower in microirrigation lateral lines than it does through the mainline and submains. The flow velocity is particularly low at the tail end of the lateral lines. Understanding how water flows in drip lateral lines helps explain this.

At the inlet of a drip lateral, the flow rate is that of all the combined downstream emitter discharges. For example, if 60 1-gallon per hour (gph) emitters are installed in the lateral line, the flow rate at the head of the drip lateral would be 60 gph, or 1 gallon per minute (gpm). For a typical drip tubing with a nominal inside diameter of 5/8 inch, the resulting flow velocity would be 60 feet per minute (fpm) or 1 foot per second (fps). The flow velocity in the drip line depends on the flow rate and the tubing size. For the same size drip tubing, the higher the flow rate, the higher the flow velocity. Using the above drip lateral as an example, downstream of the first emitter, the flow rate in the drip tube would be 59 gph; downstream of the second drip emitter, the flow rate would be 58 gph; and so on. Since the flow rate decreases along the drip lateral, so does the flow velocity. The slowest-moving water is between the next-to-the-last and the last emitter. In our



example, the flow rate in this section is only 1 gph. For the same 5/8-inch drip tubing, the flow velocity would be only about 1 fpm in this last drip line section.

The total travel time of water along a drip lateral line therefore depends on four factors:

- The length of the drip lateral
- The number of emitters installed in the lateral line
- The discharge rate of the emitters
- The inside diameter of drip tubing

Knowing these factors, the drip lateral line travel times can be calculated. But the easiest way to determine the travel time is to measure it in the field.

### **Field Measurement of Travel Times**

Microirrigation water travel times can be measured by “tracing” the movement of injected chlorine through the system. Injecting chlorine into the irrigation system is a recommended microirrigation system maintenance procedure. The presence of chlorine in the discharge from emitters can be easily monitored using a pool or spa chlorine test kit. The chlorine’s passage through the microirrigation system can be readily traced using this technique, and the water travel time easily determined. The recommended procedure is as follows:

**Step 1:** Start up the microirrigation system and allow it to come to full pressure. If the microirrigation system has not been flushed recently (pipelines and lateral lines), this should be done now. Allow the microirrigation system to return to full pressure after flushing.

**Step 2:** Begin injecting chlorine so that the chlorine concentration in the irrigation water is approximately 10 to 20 parts per million (ppm). Note the time when injection begins.

**Step 3:** Go to the emitter at the head of the lateral farthest (hydraulically) from the injection point. Using the chlorine test kit, monitor the discharge from that emitter, and note the time when the chlorine registers on the test kit. The time from the start of the injection to when the chlorine registers on the test kit is the travel time of water through the mainline-submain system.

**Step 4:** Go to the last emitter at the tail end of the lateral you just monitored (the lateral farthest from the injection point). Monitor discharge from this last emitter until chlorine registers on the test kit and note the time this occurs. The time from the start of the injection to when the chlorine registers on the test kit is the travel time of water through the entire microirrigation system.

Determining travel time through an irrigation system is important to know how long to allow the system to run following fertilizer injection. If done accurately, it needs to be done only once.



### **Post Injection Irrigation Times**

To insure fertigation uniformity it is important that irrigation continue following an injection. This accomplishes two things. First it allows the injected material to be cleared from the microirrigation system. Second, it maximizes the fertigation uniformity, since all emitters will have discharged nearly the same amount of injected material by the time the irrigation stops.

Clearing the microirrigation system of the injected material is often important to minimize emitter clogging. For example, leaving fertilizer in the system may encourage biological growth (e.g., biological slimes), which can lead to emitter clogging. Leaving materials containing calcium (e.g., gypsum or calcium nitrate) in the system may lead to chemical precipitation of calcium carbonate (lime), which may also cause emitter clogging. Time and temperature enhance chemical precipitation. The exception to this recommendation may be the injection of system maintenance products such as chlorine or acid. It may be desirable to leave these products in the system at shutdown to maximize their effects and minimize clogging problems.

Just as it takes time for the injected material to travel through the microirrigation system once injection starts, it takes an equal or greater amount of time for the injected material to clear out of the system. The injected material first clears from the head of the system, and the last point to clear is the emitter hydraulically farthest from the injection point. This is just the opposite of what occurs when injections begin, and it balances the amount of injected materials discharged from emitters throughout the microirrigation system. This gives a uniform fertigation application.

Field evaluations have been done on a single drip lateral line to evaluate the impact on chemical application uniformity of varying the injection and postinjection irrigation times. The results of some of these evaluations showed that excellent chemical application was achieved when

- The injection period was equal to or greater than the water travel time to the end of the drip lateral and
- The point injection irrigation time was equal to or greater than the lateral line's water travel time.

This suggests that there are two irrigation strategies to avoid. First, avoid injection periods that are less than the microirrigation system's water travel time to the end (hydraulically) of the system. Second, an injection should always be followed by a period of "clean" (nonfertigated) water irrigation. This postinjection irrigation should be at least as long as the water travel time to the end of the system. The worst fertigation uniformity results from too short of an injection period (less than the end-of-system travel time) followed by immediate microirrigation system shutdown. In fact, field measurements and laboratory studies have shown that clearing injected materials from a microirrigation system takes even longer than it does to originally move the injected material through the system. Flow velocities at a pipe or tubing wall are very small (theoretically zero), so some of the injected material "hangs up" on the pipe or tubing walls and takes quite a while to clear from the system.



## **Best Management Practices Recommendation**

When using a microirrigation system to apply fertilizer or other injectable materials, we recommend allowing these steps to achieve a fertigation as uniform as the microirrigation system's irrigation uniformity:

**Step 1:** Determine the length of time that it takes water and injected material to travel from the injection point to the emitter farthest away hydraulically. See the section "Field Measurements of Travel Times" for specifics on how to do this.

**Step 2:** Start the microirrigation system and allow it to come to full pressure before starting injection.

**Step 3:** Inject the chemical over a period at least as long as it takes for water and injected materials to reach the emitter farthest away hydraulically from the injection point (determined in Step 1). Longer injection periods slightly improve fertigation uniformity.

**Step 4:** Stop the injection but continue running irrigation water for a period of at least as long as the water travel time to the emitter farthest away hydraulically from the injection point. An even longer postinjection irrigation period further improves fertigation uniformity. This postinjection irrigation period is very important. Do not simply shut down the irrigation system when you stop injecting.

### **C. System Maintenance**

#### **Flushing**

The amount of flushing required to maintain the system depends on the quality of the water that you are irrigating with, and how often your system is being used. Systems using surface water often have problems with algae and other organisms growing in the tubing, and this can lead to emitter plugging. Additionally, fine silt and clay that pass through the filters can end up accumulating in the system. By comparison, clean well water may require minimal filtration, and algae may be much less of a problem.

In general, the irrigation system should be designed with clean outs on all lateral lines. These should be flushed at the start of the growing season for certain, and more frequently if there seems to be material accumulating in the system. Individual hoses should be flushed at least on an annual basis, preferably at the end of the growing season, and more frequently if plugging is observed. Some growers flush their entire system on a monthly basis, while others find it necessary to do only once a year.

Self-flushing end assemblies for drip hoses are used by some growers. They can be very effective at purging any silt or solids that end up at the end of the drip line. Occasional failures to seal can be annoying, and weeds tend to accumulate where the purged water is deposited. They should be considered as an option in situations where there is a fairly large load of suspended material going through the system. Organic growers who are fertigating with hydrolyzed proteins should definitely consider self flushing hose end



assemblies. Since organic growers can't use chlorine, flushing their irrigation systems on a regular basis is going to be essential to prevent clogging following fertigation with organic materials.

### **Chlorination to Control Algae and Bacterial Slimes**

Chlorine is often added to irrigation water to oxidize and destroy biological microorganisms such as algae and bacterial slimes. While these organisms may be present in water from any source, they are most likely to be present at high levels in surface water from rivers, canals, reservoirs and ponds.

When water containing high levels of microorganisms is introduced into a microirrigation system, emitters can become clogged. Using good filters (such as media filters) and acidifying the water can cut down on organic clogging, but the best way to deal with the problem is to add a biocide such as chlorine.

Dissolving chlorine in water produces hypochlorous acid, which becomes ionize, forming an equilibrium between the hypochlorous acid hypochlorite, referred to collectively as the *free available chlorine*. Hypochlorous acid is a more powerful biocide than hypochlorite. Acidifying the water tends to favor the production of hypochlorous acid and thus makes the chlorine added more effective. *It is important not to mix chlorine and acids together*, since this causes the formation of chlorine gas, which is toxic.

### **Sources of Chlorine**

The most common sources of chlorine are sodium hypochlorite (liquid), calcium hypochlorite (powder or granules), and chlorine gas.

Sodium hypochlorite is usually available with up to 15% available chlorine. To determine the chlorine injection rate when using sodium hypochlorite, the following formula can be used:

$$\begin{array}{ccccccc} \text{Chlorine} & \text{I} & \text{System} & & \text{Desired} & & \text{Strength of} \\ \text{Injection} & & \text{flow} & & \text{chlorine} & & \text{chlorine} \\ \text{Rate} & = & \text{rate} & \times & \text{concentration} & \times & \text{solution} \\ \text{(gal/hour)} & & \text{(gpm)} & & \text{(ppm)} & & \text{(\%)} \end{array}$$

Example: Determine the appropriate injection rate of household bleach (5.25% active chlorine) to obtain a 5 ppm chlorine level in irrigation system water. The irrigation system flow rate is 100 gpm.

$$\begin{array}{l} \text{Chlorine} \\ \text{Injection} = 100 \times 5 \times 0.006 / 5.25\% = 0.57 \text{ gallons/ hour} \\ \text{Rate} \quad \quad \quad \text{(gpm)} \quad \text{(gpm)} \end{array}$$

Calcium hypochlorite with 65% to 70% available chlorine can usually be obtained. In using the formula given above, note that 12.8 pounds of calcium hypochlorite added to 100 gallons of water forms a 1 % chlorine solution. A 2 % chlorine solution would require



adding 25.6 pounds of calcium hypochlorite to 100 gallons of water. Any chlorine stock solution can be mixed following the same pattern.

Chlorine gas contains 100 % available chlorine. While using chlorine gas is generally considered the least expensive method of injecting chlorine, it is also the most hazardous and requires extensive safety precautions. The chlorine gas injection rate can be determined from the following formula:

$$\begin{array}{rclcl} \text{Chlorine} & & \text{System} & & \text{Desired} \\ \text{Injection} & & \text{flow} & & \text{chlorine} \\ \text{Rate} & = & \text{rate} & \times & \text{concentration} \\ (\text{lb/day}) & & (\text{gpm}) & & (\text{ppm}) \end{array} \times 0.012$$

### **Desirable Chlorine Injection Rates**

If the irrigation water has high levels of algae and bacteria, continuous chlorination may be necessary. The recommended level of free available chlorine in continuous chlorination is 1 to 2 ppm, measured at the end of the farthest lateral with a good quality pool or spa chlorine test kit.

Periodic injection (once every two to three weeks) at a higher chlorine rate (10 to 20 ppm) may be appropriate where algae and bacterial slimes are less of a problem. How frequently chlorine injection should be performed depends on the extent of organic clogging.

Superchlorination—bringing chlorine concentrations to within 500 to 1000 ppm—is recommended for reclaiming microirrigation systems clogged by algae and bacterial slimes. Superchlorination requires special care to avoid damage to plants and to irrigation components. Grape vine roots are susceptible to chlorine injury. If you are contemplating this procedure, it would be advisable to discuss it with your farm advisor or viticultural consultant.

### **Precautions While Chlorinating**

The following precautions should be followed when performing chlorination:

- Inject the chlorine upstream of the filter to help keep the filter clean and to allow the filter to remove any precipitates that may be caused by the chlorine injection. Chlorine is a very effective oxidizing agent and will cause iron and manganese present in the water to precipitate and clog the filters.
- Chlorine compounds should be stored separately in fiberglass or epoxy coated tanks. *Acids and chlorine should never be stored together.*
- Do not inject chlorine when fertilizers or other chemicals are being injected, since the chlorine may destroy the effectiveness of these compounds
- When mixing stock chlorine solutions, always add the chlorine source (dry or liquid) to the water, not vice versa.



**Acidification**

Sulfuric acid is used to acidulate high bicarbonate water to reduce the pH to more reasonable levels of 6.5 to 7.0. It is a very corrosive material, and requires care and special handling. When mixed with water, it gives off heat. Concentrated sulfuric acid should not be mixed with water while in stock containers. The acid is directly injected into the flowing water during irrigation. Because it is so hazardous a material, it is not routinely used in microirrigation systems unless there are specific problems that only sulfuric acid can fix. It is used mostly when there is high lime in the soil and/or high calcium content in the irrigation water. In either case, sulfuric acid will ultimately lower the pH of the both the soil and the irrigation water.

Urea sulfuric acid is an acidic fertilizer, and is a specially formulated combination of urea and sulfuric acid sold under the trade name of N-pHURIC. While still corrosive, it is much safer to use than sulfuric acid alone. It can help to acidify water, which in turn can help to keep drip lines and emitters free of calcium carbonate deposits. Higher concentrations can be used if lime deposits have caused clogging problems in the irrigation system. It is sometimes used to bring irrigation water pH levels to 6.5 to enhance chlorine activity and effectiveness.

**Other Water Conditioners**

There are numerous water conditioning compounds that are made from polyphosphates, phosphonates, polymaleic acids and polyacrylic acid that are used as scale preventatives and sequestering agents for iron and manganese in municipal water systems, cooling towers and other places where relatively nontoxic materials are valued. Their successful use has been well documented for those applications, but for treating microirrigation systems, their use has given mixed results. One attractive feature is their relative safety and ease of handling. Unlike acids and chlorine, they are not so dangerous to handle, and they are registered for use in drinking water, so they are considered to be fairly nontoxic. Limited published information exists on the use of these materials for treating water quality problems in microirrigation systems. Grower experiences are mixed. More information on the use of these materials needs to be developed.



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